Impact of Digital Planning Tools on the enhancement of the Urban Microclimate

Case study: Grasbrook New District, Hamburg

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Hamburg, 22.06.2021

HafenCity Universität Hamburg

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Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Master of Science in the Resource Efficiency in Architecture and Planning (REAP) Program at HafenCity University Hamburg,

under the supervision of

Prof. Dr. -Ing Wolfgang Dickhaut

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22.06.2021

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Declaration of Authorship / Affidavit

This declaration has to be submitted together with the thesis

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Hereby I declare that I have written this thesis with the title

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Acknowledgements

I would like to mention my deepest gratitude to my advisors Wolfgang Dickhaut and Angeliki Chatzidimitriou for their knowledge and acute precision in guiding me with absolute disposition. Also, to the professionals interviewed for this Master Thesis, whose generosity and expertise constitute a fundamental part of this research.

To Julia Sievert, the kickstarter who made me consider microclimate as a wonderful exploration topic, and who guided me along these months with much patience and kindness. To the GRACIO Team and DCS for being always supportive and a reference for professionalism during these remote-working times.

To HafenCity University and the REAP International Program, for being an academic institution which serves as a bridge for many to take the leap into a foreign education experience.

To Geronimo and Clementina, my true motivation and pillars to push things forward. Thank you for teaching me with your unconditional happiness and spirit. You are my best team.

To my beloved and missed Venezuelan family, projecting always love and support despite the distances.

To the unforgettable REAPies, who made this Master experience so fun, I am grateful for being part of such a special 10th generation.

I am thankful for the entire journey which has brought me up to this point in my life with the support of many, and for the process of this research to let me see now architecture from another dimension.

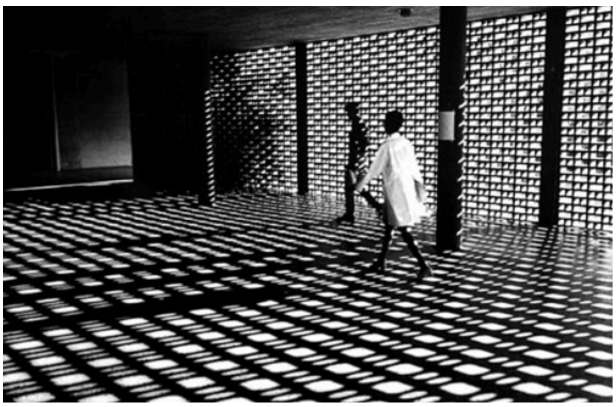

Figure 01. Tropical architecture of plaza cubierta, in Caracas, Venezuela. *Note*: Photo of Paolo Gasparini, adapted from from *Ciudad Universitaria. Carlos Raúl Villanueva. Caracas, Venezuela* [pinterest post], by A. Mondolfi, n.d.

Abstract

The consolidated digital Era in which we have stepped into, in combination with the disadvantageous consequences of globalization such as the outbreak of pandemics, stresses the urgent necessity to re-design new methods to approach city planning in an innovative way. Partly, the relevance of optimizing the planning processes of cities, is due to the human need to socialize in its urban open spaces, areas where at the same time, microclimate conditions are most exacerbated. This study focuses on understanding the impact of digital tools for the enhancement of the urban microclimate, within the context of city planning. For this, a case study area is selected at neighborhood scale, in the new District of Grasbrook, one of the upcoming urban developments with an integrative approach for the city of Hamburg. The methodology to address the posed research questions involves a qualitative phase of literature review and expert interviews, followed by an experimental phase of microclimate assessment, through analog field measurements and digital computational modelling and simulations, using the microclimate assessment software Envi-Met to assess outdoor thermal comfort. The resulted outcome of the methodology provides findings from the design and technical perspective, translated into a series of general recommendations which should potentially provide views on a more efficient incorporation of microclimate assessment into the city planning process.

Keywords: city planning, climate, climate adaptive design, computational tools, data, district scale, Envimet, Grasbrook, human thermal comfort, microclimate, microclimate assessment, outdoor space, simulation model, sustainable development.

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Acronyms

BUE: Behörde für Umwelt und Energie
CFD: Computational Fluid Dynamic
DCS: Digital City Science Group
DWD: Deutscher Wetterdienst
EBM: Energy Balance Model
IR: Infrared
LAD: Leaf Area Density
PET: Physiological Equivalent Temperature
PMV: Predicted Mean Vote
PPD: Predicted Percentage Dissatisfied Index
SVF: Sky View Factor
SWR: Short Wave Radiation
UGI: Urban Green Infrastructure
UTCI: Universal Thermal Climate Index

Chapter 1

Introduction and Research Overview

1.1. Background and Relevance

The starting point for this research is focused on the need to question the future of city planning. It is now evident that the amount of people living in urban settlements has been evolving at an exponential pace since the 1960s, with a greater increase in the most densely populated areas and megacities (United Nations, 2018). For planners, this implies a bigger effort to respond faster, with efficient solutions. The process of decision-making among actors involved in the planning of cities should be then reviewed and adapted to the new Era we are stepping into.

After the outburst of the COVID-19 crisis of 2020, it has now been globally understood that we have irrevocably entered a Pandemic Era (Batty, 2020). Before the pandemic, cities were already regarded as a network of overlapping dynamics, and after the known consequences of this global outbreak, urban activity is now abruptly conditioned by the use of remote and digital working tools to keep up with the needs of society. This should therefore be considered to address an urgent streamlining of the existing city planning tools as well.

Despite this situation, the open space in cities remains the common ground of the urban realm where social diversity happens. It is also the space where microclimatic conditions are mostly exacerbated. Microclimate as a phenomenon has been proven to be directly related to the urban environment of cities and as such, has become a relevant field of study since the first half of the twentieth century (Roesler and Kobi, 2018) coinciding with what has been known as the rise of the post-industrial cities and the wake of globalization (Nilsson, 2015). Nevertheless, the fields of research for the topic of Microclimate bring together a broad range of disciplines such as architecture, urban planning, landscape, water management, anthropology, biometeorology, climatology, urban physics, thermodynamics, public health and governance, to mention a few. From the perspective of urban planning, its influence on the urban environment has been known to affect energy consumption patterns of cities as well as the physiological conditions of human thermal comfort (Salata et al., 2016; Moonen et al., 2012). Grimmond et al. (2010) in their study about climate and sustainable cities, have already stressed the importance of trans-disciplinary collaboration in the topic of microclimate research for the development of cities in the last decade. It is therefore urgent to exchange knowledge on how to approach the problem of microclimate development more effectively. Ultimately, achieving proper calibration of microclimatic conditions in an urban environment can contribute to overarching goals such

Figure 02. Hamburg, a city of urban regeneration.
Note: Adapted from *Port redevelopments Hamburg, HafenCity*, by LSE Cities, 2013.

as the optimal use of the common open space in cities (Salata et al., 2016) and thus, mitigation of societal inequality.

The necessary adaptation process for the future of city planning should derive into a common platform where all stakeholders involved in urban development are capable of exchanging ideas and making decisions in a faster and more effective way. Since the decade of the 1970s, computer modelling techniques are used for the simulation of microclimate conditions in urban environments, Envi-Met being one of the most widely used lately (Toparlar et al., 2017) (Albdour & Baranyai, 2019). But as the network of cities have become increasingly dynamic, the complexity and time-consumption of these tools are lagging behind in regards to the pace of decision-making.

1.2. Aim, Objectives and Scope of the Study

Aim of the Research

The aim of this research is to understand how the implementation of computational tools can contribute to the enhancement of microclimate conditions in urban environments, and how these digital methods to assess microclimate be more easily adapted into City Planning processes. The research will be focused on the Grasbrook new District competition, as an example case of urban regeneration which already holds sustainable development considerations. This will be carried out through a qualitative and quantitative method approach, where based on literature review and following interviews with microclimate experts, a microclimate model and simulation will be performed, to finally gather a series of recommendations for the optimization of the represented output data in the form of results for the final user.

Objectives

Based on the research aim stated, two main objectives are set to achieve this goal: the first, is to identify possible hurdles found in the use of digital microclimate tools and the second, is to understand how can the communication and representation of results be more understandable for its end-user. In the end, both objectives should contribute to the aim of assembling unified recommendations for the incorporation of microclimate in the future of City Planning.

Scope of the Study

The scope of the study is bound to the tasks performed along the methodology in order to fulfill the mentioned objectives. In order to match the findings of the interview phase to the subsequent phase of the methodology, the selected experts for the interviews will be limited to the context of the field of microclimate assessment and planning within the European region. Furthermore, this study will be time-bound to the use of one single microclimate software, supported by literature review, and the simulation will cover the assessment a one-day scenario of a limited area within the neighborhood scale, corresponding to the case study of the new Grasbrook District development. The findings from the methodology will be summarized as recommendations oriented towards the set aim of this research.

1.3. Research Questions

The main research question defines the overall objective and scope for this study based on the previous chapter. It also contributes partly to the structure of the proposed methodology. This will be supported by two complementary sub-questions.

Main research question: ***How can computational microclimate assessment tools ease its incorporation into the city planning process?***

The first sub-question formulated will be addressed through the qualitative part of the methodology, performed through the interviews. The interview process will be oriented towards experts in different realms related to microclimate assessment who have used computational tools. Although the scope of the question includes all types of digital microclimate assessments, the study intends to explore further this question with the use of one specific software.

Research sub-question 1: ***What difficulties are found in the communication of the output of a microclimate assessment software for actors involved in the city planning process?***

The second sub-question will be addressed through the empirical phase of the methodology of a microclimate simulation based on the findings during the interview phase. This question is specific to the case study selected. The expected findings from this question should complement the answers sought out for the first two questions of this research.

Research sub-question 2: ***How can the microclimate assessment through simulations of the case study (Grasbrook) become more understandable for the end-user in the realm of city planning?***

Chapter 2

Research Methodology

The methodology for this research is assumed as a mixed method approach. It comprises a combination of a qualitative and quantitative research methods throughout its different stages. The qualitative approach is relevant at an early stage during the review of related literature and expert interviews; as well as for the outcome of this research in the form of recommendations that hold a more holistic perspective. As a complement, the quantitative aspect of this research is directly related to the empirical processes of field measurements and computer simulations performed through the use of the Envi-Met software related to microclimate. A mix of primary analyses through on-site data collection, and secondary analyses based on previous studies when defining criteria for the microclimate software parameters is necessary for the modelling and simulation phase. A graphic overview of the methodology (Figure 03) to be implemented in this research consists of the following Phases:

***Phase 1:* Literature Review.**

The literature review serves two main purposes and it is therefore divided into two types of literature consulted, referring to conceptual and technical material. The first, more conceptual type of literature, is to understand the context of the problem from a historical and social approach. Topics covering the evolution of city planning, the relevance of urban microclimate and understanding digital-based microclimate assessment through computational tools will be reviewed. From this chapter of the literature research, it is expected to be identified what adaptations will be necessary for the future scenarios of cities. This contributes to the formulation of the main and supporting research questions.

The second type of the literature reviews mostly technical articles from scientific journals. This helps cover the basic concepts of microclimate assessment, from relevant fields of expertise, such as biometeorology and physics. This will further support the structure of the interview process with experts as well as the subsequent modelling and simulation process, phases 2 and 3 of the methodology.

***Phase 2:* Interviews with Microclimate Experts, in the context of Computational Tools.**

Following the Literature review, the next step in the methodology will be to perform a series of interviews to experts from diverse backgrounds who have used computational tools for microclimate assessment. From this, the objective is to obtain a broader perspective of the benefits and disadvantages of including computational tools into the microclimate analysis; how experts have applied their results into the projects and what space for improvement they suggest for the better planning of cities.

***Phase 3:* Case study selection, data collection and computational simulation.**

The third phase of this research consists mostly of empirical methods of performing a microclimate assessment, through analog and digital processes of field measurements and digital simulations; based on the preliminary findings from the interview phase. Since the overall objective of this research is to assess the relevance of digital microclimate tools in the context of city planning, the simulation will be focused on assessing outdoor thermal comfort, a highly relevant Index for many stakeholders involved in the development of sustainable cities.

At this point, the district selected as a case study will be presented and briefly analyzed. As a second step, the required data for the simulation will be gathered from a combination of primary and secondary data collection processes, including criteria and preliminary recommendations derived from the field measurements process. The software used for the microclimatic simulation of a spatial model of the case studied will be Envi-Met Science, version 4.4.5. The objective of the simulation is to visually understand how the output data of the microclimate conditions of the District are represented differently than that from an analog process, and what possible hotspots can be identified and better assessed for city planning, through the use of the digital tool.

***Phase 4:* Analysis and Discussion.**

Once the experimental phase is concluded, the analysis and discussion of the outcome will be focused on a joint assessment between Phases 2 and 3 of this research. The results will be compared to the previous insights and challenges found during the interview phase of the research. The reflections gathered from the literature reviewed will also support this discussion. The conclusions of the research are oriented towards the assembly of a series of recommendations for the evolution of microclimate digital tools, in terms of its understandability to the end-user. The last chapters will additionally focus on explaining the limitations of the study as well as recommendations for future research in the related fields.

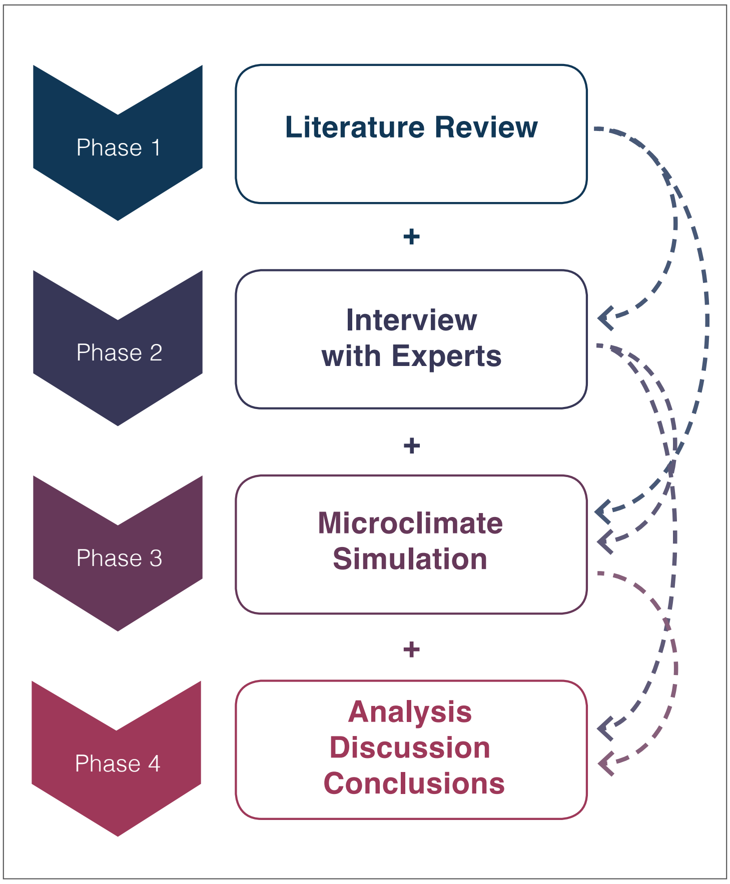
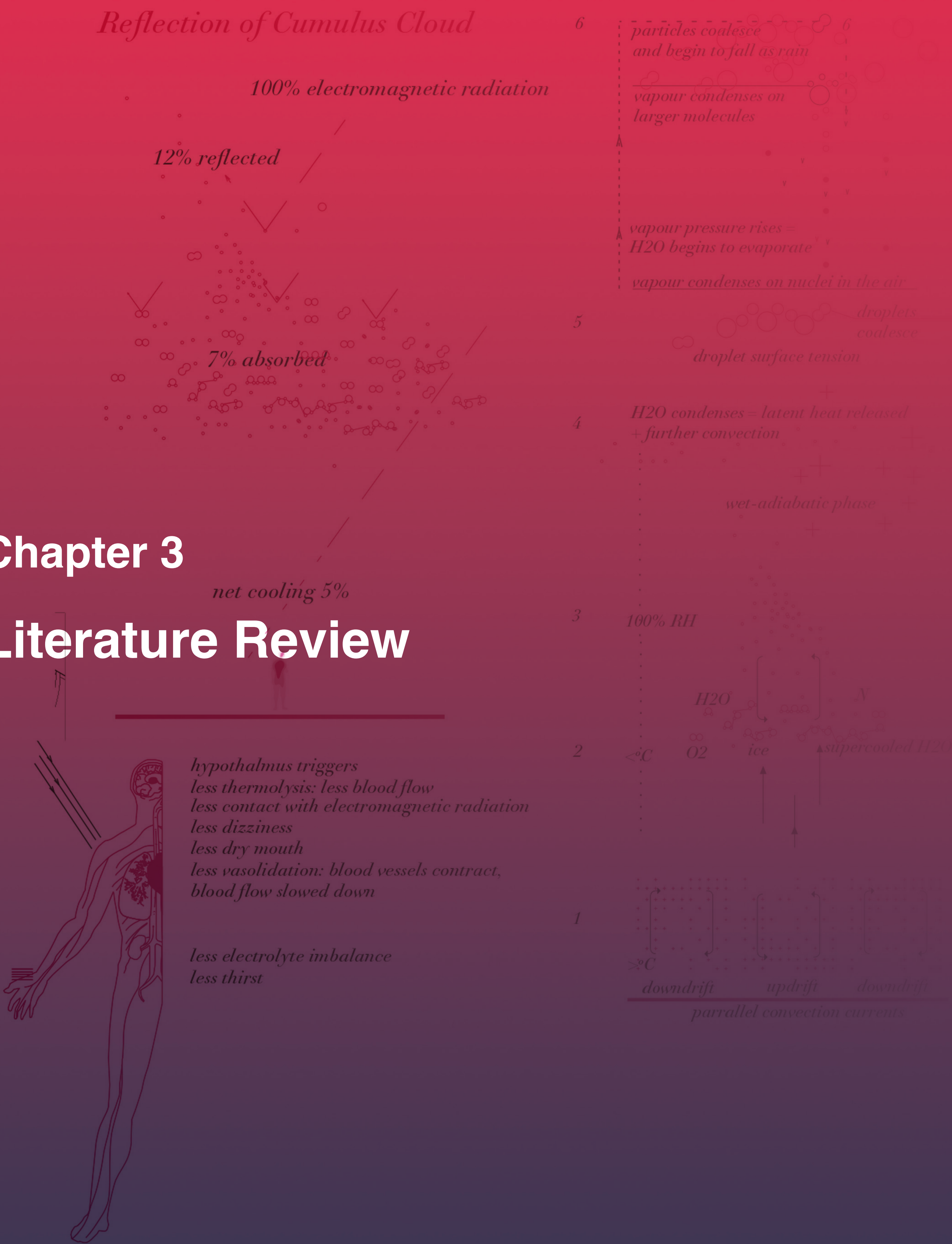


Figure 03. Graphic overview of the proposed methodology (author, 2021).

Chapter 3

Literature Review



Figs. 8 b and 8 c

3.1. Brief overview on the evolution of City Planning

Cities can be understood as one of humanity's earliest inventions (Kotkin, 2007). Throughout their evolution, they have proven their capacity as dynamic systems to adapt to change. Historically, some of the most relevant planning reforms in cities, like the urban sanitation movement, have happened as a consequence of epidemic outbreaks during the rapid industrialization and urbanization processes, such as cholera or typhoid across cities in the United States (Corburn, 2012). Another example of this were the reforms undertaken in the former city of Bombay, where the insanitation and overcrowding conditions accelerated the effects of the bubonic plague towards the end of the XIX century. Regulatory measures such as light and ventilation for internal spaces were considered fundamental solutions which lead to the first urbanization process of the city (Indorewala, 2018). Other largely populated cities, like London or Shanghai, overcoming epidemics during the XIX and XX century, provided additional gainful knowledge in understanding the strong connection between public health and urban planning.

The XXI century poses a new scenario cities must face in terms of adaptation and evolution: this is already considered a post-pandemic Era (Batty, 2020). It has been strongly discussed that globalized social dynamics will further accelerate the recurrence of pandemics and its spread across cities (Nuzzo, 2016). But globalization has also contributed to the latest advances within societies, science and technology. This has resulted into the appearance of new disciplines involved in cities development, and it is no longer only the task of an urban planner, but now it is referred also to city science, urban science, or even urban spatial data science (Sikder, 2020). Current urban activities in globalized cities are increasingly dependent on the use of data to formulate new tools for development. As mentioned by Sikder (2020) in an ever more digital-oriented society, it can be estimated there will be a need for urgent adaptations to different scenarios, especially when facing the possibility of future pandemics, and involved decision-makers need to respond faster.

Jackson and Simpson (2014) provide a broad overview of the existing realms of research dedicated to the development of modelling tools, to advance towards the achievement of truly sustainable cities. Within one of the research themes discussed, the first urban models originated in the 1960s are explained as "computer simulations of the ways cities function; they translate theories into forms that are testable and applicable without experimentation on real environments" (Jackson and Simpson, 2014, p.68). This approximation to

Figure 04. Study of the effect of cirrus clouds on the human body, for the Jade Eco Park project in Taiwan, by Philippe Rahm.
Note: Adapted from *Thermal Sensations,* by S. Roesler, 2018, p.114. Copyright 2018 Birkhäuser Verlag GmbH, Basel.

the topic of city modeling has evolved since then, as cities have grown to be understood not as static models but as dynamic systems, and the role played by data has become increasingly relevant. "These models are not vehicles for testing hypotheses _they are more likely to be frameworks for assembling relevant information and for formal and informal dialogues; often used as tools in community consultations and other participative processes of decision support" (Jackson and Simpson, 2014, p.69).

It can therefore be understood that new adaptation to innovative city planning processes are upcoming. Of course this must be achieved without compromising fundamental purposes such as diminishing inequality in society and maintaining a proper quality of life for the majority of the population, especially when gap between the developed and underdeveloped urban centers is increasing in terms of population (Figure 05). Cities will surely adapt once more, but should strive to preserve its essence, for example, to be a common space in which society can dialogue.

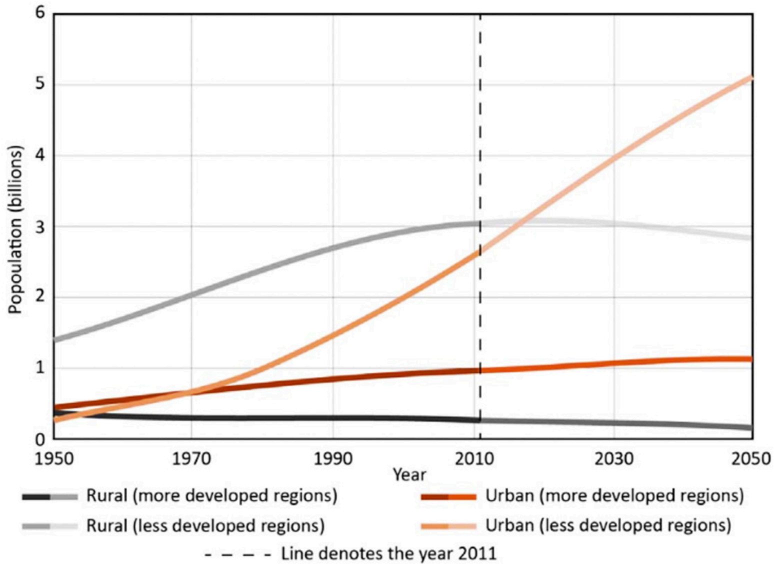


Figure 05. World population in urban and rural areas.
Note: From *A review on the CFD analysis of urban microclimate, by* Y. Toparlar et al., 2017, p.1614. CC-BY-NC.

3.2. Relevance of the Urban Microclimate

As explained by Roesler and Kobi (2018) the term Microclimate was originally coined by Rudolf Geiger and Albert Kratzer in the first half of the XX century, referring mostly to the climate measurement differences between urban and rural areas. This first approximation to the concept came from the fields of meteorology and geography. In the following years, it was further investigated within the realms of physics and thermodynamics (Roesler and Kobi, 2018) and has expanded even more in recent years to a greater variety of scientific disciplines (Moonen et al., 2012), exposing the importance of transdisciplinary understanding of the complexity of climate in cities. Nevertheless, the focus behind the research by Roesler and Kobi (2018) is a more contemporary approach to the concept of microclimate beyond solely the scientific understanding of the phenomenon. It refers to the idea that microclimate in urban areas can be seen as a man-made artifact, as a consequence of the anthropogenic effects from alterations to the environment through, for example, its architecture or human activity. Therefore, the decision-making process of city planning can potentially determine also the outcome of its urban microclimate.

It can then be understood how microclimate is intrinsically bound to cities; it is affected by the built anthropogenic environments, but at the same time it conditions the way cities are used in their open spaces. Chatzidimitriou and Yannas (2016) explain how “more diversity in thermal conditions encountered across a square or courtyard may increase pedestrians’ interest in these spaces or perhaps even the probability of comfort sensation for different people at different times of day or seasonally”. The open space of cities should then be always considered the common ground for society where diversity happens (Chokhachian, 2019) and also where microclimate conditions are most exacerbated.

Some of the known consequences of the anthropogenic activities affecting negatively the microclimate of cities include higher temperature, poorer ventilation flows and lower air-quality (Grimmond et al., 2010). These are factors which have a direct impact on the quality of open spaces, and also on its users. It can therefore condition the frequency and length of use of public areas within a city, depending on its comfort levels. As stated by Moonen et al. (2012) and Chatzidimitriou and Yannas (2015), the shape of the urban form can, in a smaller scale, determine human behavior in open spaces; while in the larger scale, can potentially contribute to the mitigation of Urban Heat Island effects in cities.

In order to relate in a quantifiable way the impact of microclimate to human activity, the understanding of Outdoor Thermal Comfort was created as one of the most relevant microclimate factors used today. It is defined as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” (Ashare Standard 55-2017, as cited in Zhang et al. 2020, p.2). Different thermal indexes have been created to assess Outdoor Thermal Comfort, such as the Predicted Mean Vote (PMV), the Universal Thermal Climate Index (UTCI) or the Predicted Percentage Dissatisfied Index (PPD). Nevertheless, most are determined by similar environmental and physiological parameters of the human energy balance model. Matzarakis and Amelung (2008) support in their study the use of the

Physiological Equivalent Temperature (PET) thermal index, above the others previously mentioned. The added value of this Index is its consideration not only of meteorological parameters like air temperature, humidity, wind and mean radiant temperature, but also the thermo-physiological parameters of human comfort affected by clothing and activity (Figure 06). It is also regarded as a relevant Index within German Standards for Urban and Regional Planning, according to Deb and Alur (2010).

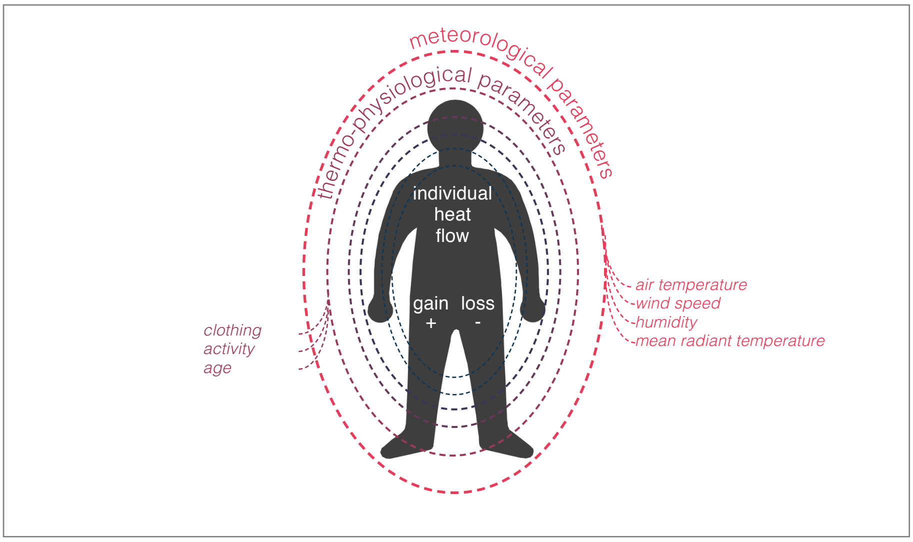


Figure 06. Diagram of the Energy Balance Model (own figure).
Note: Adapted from *Physiological Equivalent Temperature as Indicator for Impacts of Climate Change on Thermal Comfort of Humans*, by A.Matzarakis and B.Amelung, 2008. Copyright Springer Science + Business Media B.V 2008.

As it can be seen from the different parameters constituting the PET index, when reaching adequate levels within the regulated scale (Table 01), it enhances, not only, the individual's perception of being in a healthier environment, but could even guarantee a higher level of citizen engagement within the open spaces of cities, and therefore it is of ultimate importance for the realm of City Planning. In this sense, addressing microclimate through the assessment of Outdoor Thermal Comfort can consolidate better interactions between health, climate and cities.

Table 01. Classification of the numerical thresholds for the thermal indices along with physiological conditions and thermal perception.
Note: From *Thermal discomfort analysis using UTCI and MEMI (PET and PMV) in outdoor environments,* by M. Asghari et al., 2019, p. 559. Copyright 2019 Royal Meteorological Society.

Thermal perception	*Indices range*		
	PMV	*PET*	*UTCI*
Very cold[1] (extreme cold stress[1,2])	−3	< 4	< −40
(Very strong cold stress[2])			−40 to −27
Cold[1] (strong cold stress[1,2])	−2.5	4–8	−27 to −13
Cool[1] (moderate cold stress[1,2])	−1.5	8–13	−13 to 0
Slightly cool[1] (slight cold stress[1,2])	−0.5	13–18	0 to +9
Comfortable[1] (no thermal stress[1,2])	0	18–23	+9 to +26
Slightly warm[1] (slight heat stress[1])	0.5	23–29	
Warm[1] (moderate heat stress[1,2])	1.5	29–35	+26 to +32
Hot[1] (strong heat stress[1,2])	2.5	35–41	+32 to +38
(Very strong heat stress[2])			+38 to +46
Very hot[1] (extreme heat stress[1,2])	3	>41	>+46

[1]PET and PMV
[2]UTCI

3.3. About the Use of Computational Tools

According to Zhang et al. (2020), the assessment of Outdoor Thermal Comfort has been conducted mostly by methods of field assessment through data measurements or by computer simulation analysis. However, the use of computer-based tools in comparison to field measurements for the assessment of microclimate poses advantages such as the possibility to interpret multiple scenarios through simulations or providing a spatial representation of the data gathered, as explained by Toparlar et al. (2018). Their research presents an overview of the variety of observation versus simulation methods frequently used for the evaluation of microclimate (Figure 07) and the relevance of computational fluid dynamic (CFD) models within the simulation methods, for real-case scenarios. As it can be seen from Figure 08, most of these studies are done in developed urban centers across the globe, which denotes the clear correlation between the digital assessment of microclimate with the availability of input data.

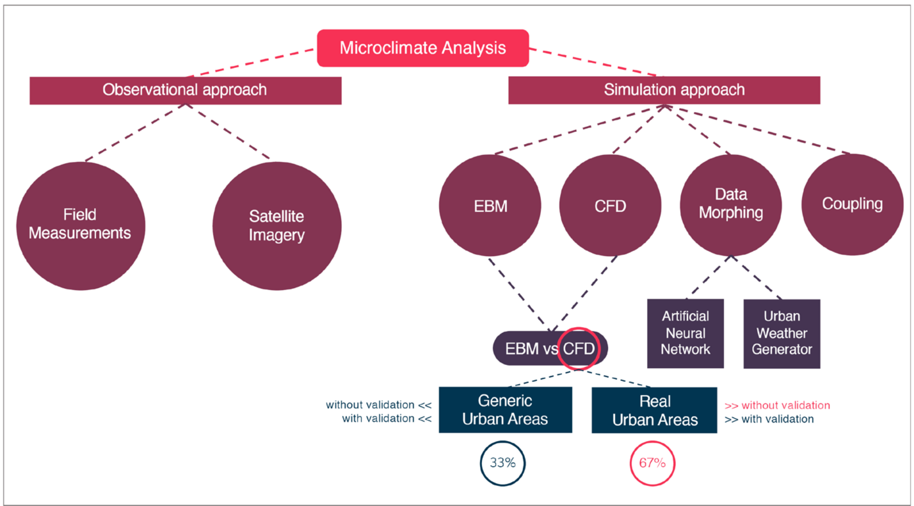


Figure 07. Different Microclimate Analysis Methods (author, 2021). *Note:* Adapted from *A review on the CFD analysis of urban microclimate, by* Y. Toparlar et al., 2017. CC-BY-NC.

In another publication by Toparlar et al. (2017) one of the conclusions presented supports the use of the CFD desktop software Envi-Met by more than half of the studies consulted, above other desktop simulation software. This, mainly because of the possible combinations of phenomena which can be assessed simultaneously in a larger scale simulation. This makes Envi-Met a relevant CFD desktop software to study; nevertheless, the authors also state still a few drawbacks from the physical model of this digital tool, which leaves open the possibility for further development. Salata et al. (2016) mention that despite the pressing necessity to acknowledge microclimate conditions for proper city development, the advances have not been fast enough due to the complexity of the desktop tools, which require much time and resource investment. The assessment through these simulation models does not seem yet as common among planners as it should be. A cause for this can also be due to the type of user or discipline to which they are designed for.

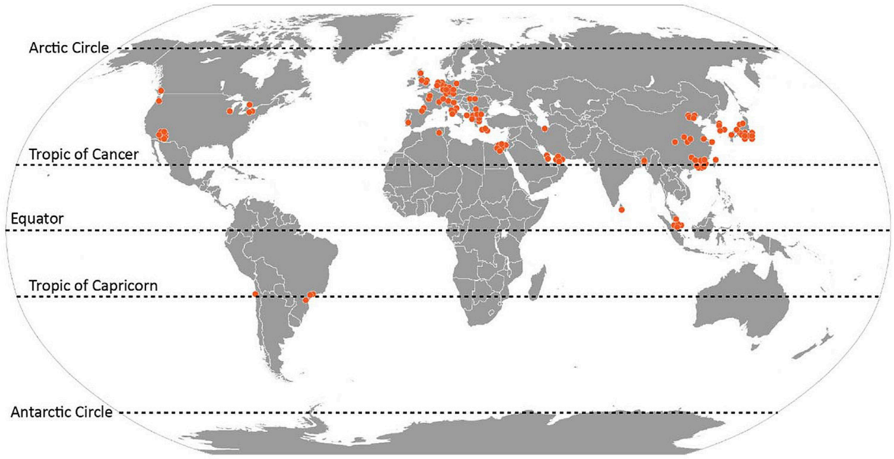


Figure 08. Distribution of analyzed CFD microclimate studies focusing on real urban areas
Note: From From *A review on the CFD analysis of urban microclimate, by* Y. Toparlar et al., 2017, p.1628. CC-BY-NC.

A sought-after solution pushed by this digitally-driven society, with an increasing pace of rapid exchange, is a growing tendency to consider within the research of microclimate assessment, the use of more collaborative tools, strengthening participatory processes and multi-level governance perspectives, instead of top-down approaches (Bottero et al., 2018). The objective behind this approximation is to plug-in more tools to the existing robust computer hardware, in order to capture not only the factors of the physical phenomena but also other domains related, such as the sociological factors affecting microclimate. This tendency brings researchers closer to the use of agent-based models, for example, to achieve faster assessment of context-related situations, specific to each city (Negendahl, 2019).

This evolution of tools has naturally also derived into a wider range of users, beyond the realms of hard science, and allowing for actors from different backgrounds to engage in the assessment of microclimate for planning purposes. Such is the case of the Cityscope tool, a digital interface currently applicable for urban design competition assessment, with ongoing development for further applications into other realms of decision-making for functional planning processes (López Baeza et al., 2021).

Kristoffer Negendahl (2019), as a simulation specialist and civil engineer, explains in a chapter dedicated to the computational design process, how despite the proliferation of digital tools and their enhancement on the possible design choices available in each case, still the streamlining process of decision-making needs to be learned, in order to achieve real sustainable solutions for future cities. This is not only achieved by dominating the digital tools, but on the other hand, it will also depend on the degree and background knowledge on behalf of the person conducting the analysis. Naboni (2019) stresses the importance of shifting the sustainability approach towards that of a regenerative alternative, where coupling of disciplines like science and design should be sought after for new urban development, and where data and digital tools are imperative for it (Figure 09).

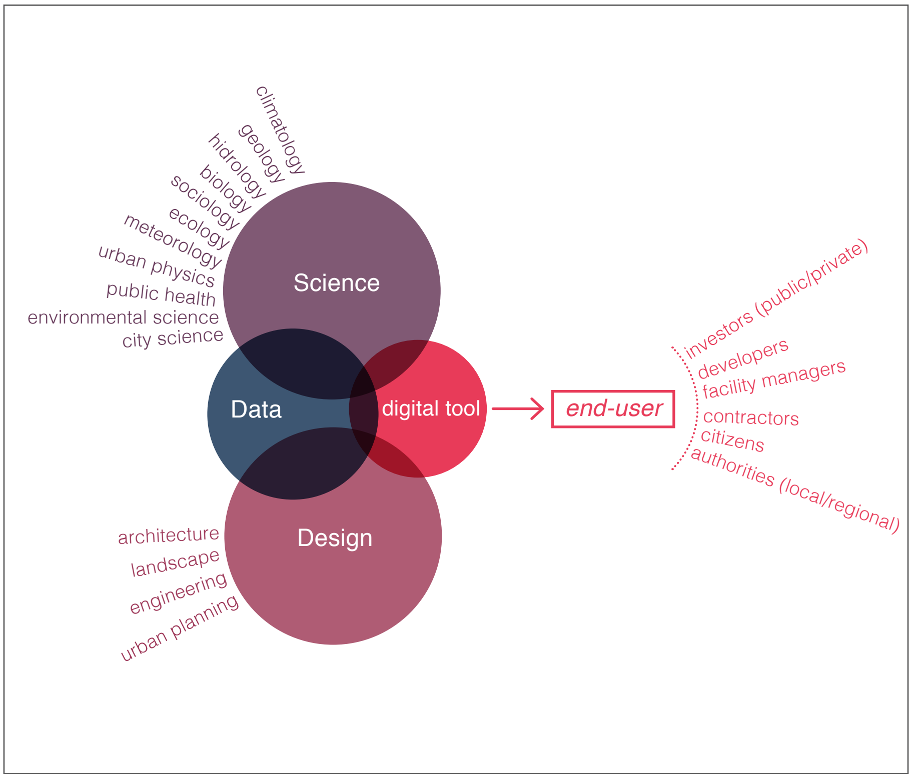


Figure 09. Diagram of interdisciplinary approach needed for the use of digital tools for microclimate development (author, 2021).
Note: Adapted from *Blending Sciences into Regenerative Design Practice,* by E.Naboni, 2019.

3.4. Research Gap from Literature Review

Computational microclimate assessment tools have come a long way in terms of technological evolution, but nevertheless are still not an intrinsical part of the planning process. Furthermore, the coupling of multiple disciplines within the planning process seems a necessary step for microclimate assessment, but how to achieve it is still a relatively recent challenge. It should then be revised whether the latest computational tools are still being developed for the profile of a more specialized user or is it also attainable to relevant actors from other fields related to the planning of cities. The characteristics of an adequate tool which could bring all involved planners one step closer to a faster and more efficient way of addressing the challenges of rapidly-growing urban centers, can still be outlined.

Chapter 4

Interviews with Microclimate Experts

After reviewing the selected literature for a broader overview on the topic, an in-depth analysis into the advantages and barriers found in the practice of microclimate assessment was necessary through the performance of a series of expert interviews.

4.1. Parameters for the Interview Process

Due to the nature of this research, a semi-structured type of interview is recommended, in order to obtain from the consulted experts a deeper insight on the topic of microclimate. As the outcome of a semi-structured interview will be mostly of a qualitative content, a thematic analysis method is selected to process the content of the performed interviews. This method consists of identifying initial common codes found among the data gathered from the different interviews, and helps to cluster them into categories and themes for a better assembly of conclusions which can be further used in the overall analysis of the thesis research (Mortensen, 2020).

The interviewees were provided an Interview Protocol (in Annex A1-A3) consisting of an Explanatory Statement, a Consent Form, and 12 open-ended questions distributed along 3 main relevant subjects: Internal Workflow related to microclimate assessment, Microclimate Assessment through simulation processes, and Decision-Making phase of the process. The interview procedure was performed individually, on-line, through recorded video-calls or telephone calls and following the same questionnaire for all interviewees, but in a flexible way during a margin ranging from 35 to 60 minutes, depending on each expert. The overall process of the interviews was executed along a period of 2 weeks, with their respective transcription of the content.

4.2. Selection Criteria for the Interviewees

The criteria for the selection of the relevant experts included selecting professionals from varied disciplines involved in microclimate assessment, all practicing within the context of European regions or, when possible, having worked close to the German context of city planning processes. This is important for a better comparative analysis of the framework of practice to which they are limited to.

After assembling a potential list of interviewees through the platforms of scientific or academic journals, as well as first-hand recommendations from other experts, a final group of 6 interviewees were selected, depending on their relevance to the topic, availability for interviews or recent publications

Figure 10. Screen captures of video interviews (author, 2021).

and practice. It was also indispensable for their involvement in the interview process, that besides coming from the field of microclimate assessment, they also incorporate computational tools into their current practice. In Table 02, the complete information of the participating experts, as well as their background and field of work can be consulted. The addressed questions revealed valuable information from the perspective of their background or professions, useful for the comparative analysis and outcome. Figure 11 depicts, based on the interview content, how the different professional realms relate to the use of microclimate assessments.

Table 02. List of interviewed experts, detailing their background and field of work (author, 2021).

INTERVIEWED EXPERT	BACKGROUND	FIELD OF WORK
Jeremy Anterola	Landscape Architecture	Integral Planning
Jana Caase	Geo-Ecology / Environmental Science	Climate Consultancy
Udo Dietrich	Building Physics	Research / Academia
Lutz Katzschner	Meteorology	Climate Consultancy
Emanuele Naboni	Architecture / Building Science	Research / Academia
Stella Tsoka	Civil Engineering / Building Physics	Research

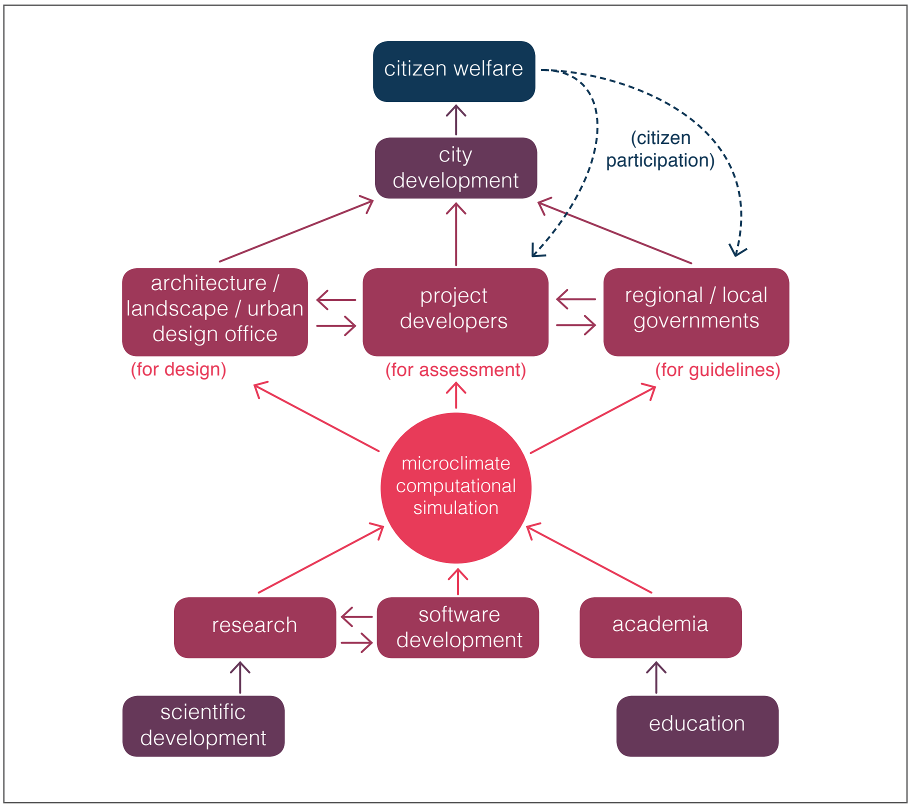


Figure 11. Diagram of microclimate assessment processes, based on content from interviews (author, 2021).

4.3. Thematic Content Analysis

After the interview sessions were concluded, a Thematic Content Analysis was performed. At this point the interviewees no longer participate in the process, and this analysis is executed individually. The first step is the transcription of the interviews audio to written form, for better review of the content. The following is an interpretation step, mostly done through the use of a digital whiteboard tool called Miro Board (see Annex A5), to break down the data from the audio transcriptions and combine the content obtained from the different experts consulted into a unified analysis. Table 04 presents a visual layout of the broken-down process from the interviews to the analysis, detailing each step of the thematic content analysis made. The most relevant themes and sub-themes, based on recurrency among the different experts consulted, are summarized in Table 03.

<table>
<tr><th>THEMES</th><th>SUB-THEMES</th></tr>
<tr><td rowspan="3">application</td><td>Analog versus Digital</td></tr>
<tr><td>When is it indispensable to use simulations?</td></tr>
<tr><td>The Goal: what for?</td></tr>
<tr><td rowspan="3">workflow</td><td>Best stage of projects for microclimate assessment?</td></tr>
<tr><td>Who performs simulations?</td></tr>
<tr><td>Team workflow for microclimate</td></tr>
<tr><td rowspan="4">hurdles</td><td>Time resource / computer power</td></tr>
<tr><td>Scale versus range</td></tr>
<tr><td>Input data</td></tr>
<tr><td rowspan="2">Expectations of results</td></tr>
<tr><td rowspan="3">output</td></tr>
<tr><td>Target: What is assessed?</td></tr>
<tr><td>Precision</td></tr>
<tr><td>representation</td><td>Translation, decoding, additional tools</td></tr>
<tr><td>communication</td><td></td></tr>
<tr><td>client / end-user</td><td></td></tr>
<tr><td>future development</td><td></td></tr>
</table>

Table 03. List of identified themes and sub-themes from the thematic content analysis (author, 2021).

INTERVIEW ACTIVITY >>		THEMATIC ANALYSIS			
INTERVIEW TOPICS >>	INTERVIEW QUESTIONS >>	CODES >>	THEMES >>	SUB-THEMES OR CATEGORIES >>	CONCLUSIONS
6 experts interviewed	*Equal set of 12 questions were made to each expert, according to the 3 topics of the session.*	*Relevant content from answers was identified and summarized in sentences*	*Synthesis process of clustering identified codes into main themes.*	*Common sub-topics are grouped into each main theme.*	*Second synthesis process, where topics are summarized into conclusions per sub-theme*

INTERVIEW TOPICS	INTERVIEW QUESTIONS	CODES
INTERNAL WORKFLOW	1. Before considering digital tools, are any other means of understanding microclimate for the cases studied considered? Maybe explain why was the use of software considered?	*(synthesis and interpretation process - answers from all experts in each question, were unified)*
	2. How often are microclimate simulations used in the projects undertaken?	
	3. Usually in the working team, what is the profession or level of specialization of the person responsible for the execution of the microclimate assessment software?	
	4. In what stage of the projects have these type of software been usually consulted? Whether it is at a conceptual preliminary phase, development or detail-level phase of the projects? Which has been the learning experience from this?	
SIMULATION PROCESS	5. If an entire microclimate simulation process is broken down into: modelling, simulation, output and analysis phases; in which stage is considered the greatest hurdles are encountered? Can you describe the type of hurdles found?	
	6. Is it attainable how much information one can set up, produce and visualize out of the output data, and can it be done timely, in order to reach the decision making phase?	
	7. How exact are the results of a simulation? What are the main uncertainty factors? How would you recommend minimizing imprecision?	
	8. How do you usually handle the data to be used? Whether it is System Database or User Database? Which are most sensible to influence the result?	
DECISION-MAKING PHASE	9. Are the results obtained used for internal decision-making among the team, or is it also something shown to the potential client? What has been the feedback on the other end when explaining the output content to the client?	
	10. Has there been any need to incorporate an additional tool to go from the results obtained through the software to the showcase of the information to a client or to the decision-making group?	
	11. Was there a specific Target to address when assessing microclimate in the projects? If so, what were the relevant parameters for this?	
	12. Do you consider there is still the need to understand or reflect on one aspect of the projects in a better way than that achieved up to now?	

THEMES	SUB-THEMES OR CATEGORIES	CONCLUSIONS
APPLICATION	**Analog vs Digital**	(set of conclusions per sub-theme)
	When is it indispensable to use simulations?	(set of conclusions per sub-theme)
	The Goal: what is it done for?	(set of conclusions per sub-theme)
WORKFLOW	**Best stage of projects to perform a microclimate assessment?**	(set of conclusions per sub-theme)
	Who performs simulations?	(set of conclusions per sub-theme)
	Team workflow for microclimate	(set of conclusions per sub-theme)
HURDLES	**Time resource / computer power**	(set of conclusions per sub-theme)
	Scale vs range	(set of conclusions per sub-theme)
	Input data	(set of conclusions per sub-theme)
HURDLES / OUTPUT	**Expectations of results**	(set of conclusions per sub-theme)
		(set of conclusions per sub-theme)
OUTPUT	**Target: what is assessed?**	(set of conclusions per sub-theme)
	Precision	(set of conclusions per sub-theme)
REPRESENTATION	**Translation, decoding, additional tools**	(set of conclusions per sub-theme)
COMMUNICATION		(set of conclusions per theme)
THE CLIENT / END-USER		(set of conclusions per theme)
FUTURE DEVELOPMENT		(set of conclusions per theme)

Table 04. Process from interviews to the thematic content analysis (author, 2021).

4.4. Findings from the Interview Process

The main conclusions extracted from the interview analysis can be summarized within the context of the found themes and sub-themes previously mentioned.

4.4.1. In regards to the Application of Digital Tools.

Analog vs. Digital Tools: An important reflection is whether analog and digital processes for assessment can complement each other, or eventually digital tools can substitute the on-site measurements usually performed for microclimate. It was understood among the different interview sessions that on-site microclimate assessment is still a fundamental analysis activity, and should be done as a first-step before deciding on running digital simulations. Prof. Dr. Lutz Katzschner, from the field of Meteorology, explains as part of his methodology "the first thing to do is to understand the climatic situation of an area or of a city. This means, either we do some experiments or we visit the site (…) so, only afterwards we use digital tools" (L. Katzschner, phone interview, March 19, 2021). There can be cases when after on-site assessment is performed, simulations are no longer necessary. Only when needed, they can be done as a subsequent step. The general agreement was that an expert on-site will usually be more accurate than a simulation for a proper microclimate analysis. When referring to the question of accuracy of a simulation versus an onsite assessment can be, landscape architect Jeremy Anterola supports the idea that "going onsite and having an expert analysis (…) will always be better than any type of simulation", but in this sense we should also question "what is the intended purpose of the assessment and at which point in time is the assessment being conducted to determine how precise the simulation can or needs to be based on the available data" (J. Anterola, video interview, March 18, 2021).

When is it indispensable to use simulations?: For this questions, diverse situations were mentioned. For example, when a more complex exchange of microclimate conditions between indoor and outdoor environments is consulted, digital tools can provide more information, while when the assessment is entirely outdoor, and the environment is not too complex, perhaps simulations are not needed. Also, if a two-seasons scenarios to be compared are too far apart, timewise, and it is inefficient to wait, a simulation can provide results sooner. When the area to be studied is complex regarding its topography or climate, it might be better to use digital simulation tools. Another case explained by Prof. Dr. Udo Dietrich, from the field of Building

Physics, is when future scenarios must be compared, "if you want to find out any prognosis (…) or any still unknown situation in urban planning (…) then it is fine to use a software, it is easier than to measure" (U. Dietrich, video interview, March 18, 2021). This is also the case when a proposal shall be compared to the current status of the site. Finally, a relevant case mentioned is when the area to be assessed is inaccessible or it is an international site, it might be more pragmatic to work remotely and perform digital simulations to obtain results. Referring to this point, Anterola explains "desktop-based simulations are a common and validated methodology applied by architects and planners for testing how projects can potentially perform, and can be just as applicable for projects domestically - for us, in Europe - as well as abroad" (J. Anterola, video interview, March 18, 2021).

What is the goal of the endeavor?: It is important to consider that the application of simulation tools will be strongly determined by the goal of the assessment. From Anterola's experience with consultancy projects, results can be "as precise as necessary based on the expertise of the user, for example consultants. More important is the intended use of the results; experience shows that interests vary quite largely between end-user groups which can include property developers, city governments, research institutes, other designers or even the public" (J. Anterola, video interview, March 18, 2021). The goal aimed at to perform a microclimate assessment should be known by all involved actors from the start and as explained by Dr. Emanuele Naboni, architect and academic, when providing results back to a client "it is important to create a logical argumentation, depending whether it is for an assessment, for design or for guidelines that need to be made" (E. Naboni, video interview, March 18, 2021).

4.4.2. In regards to the usual Workflow.

Best stage of projects to perform a microclimate assessment: Most experts agreed the optimal moment of a project to perform a microclimate assessment would be at the beginning stages, because there are more possibilities to edit or improve the design based on the microclimatic findings and recommendations. Of course, along all phases of a project it can be done, and iteration is recommended, but it will have different outcomes regarding what can indeed be changed. Regarding this topic, Naboni states that "it depends on the decision made (…) but at any stage it can be implemented, even for the finishing materials you can change completely the size of the thermodynamic matter" (E. Naboni, video interview, March 18, 2021). In the final phase of a project it could still define last detail, but the overall result could have greater consequences, cost-wise.

Who performs the simulations within the team?: This topic varied depending on the field of work of the experts consulted, but it was understood that digital tools for microclimate can be used by professionals from many disciplines, such as architects, experts in GIS, civil engineers, meteorologists, urban planners, geo-ecologists or experts from building physics. In general, this type of activity is performed by a person who becomes a specialized user, disregarding its original profession, and in some cases they do not come into play for the other realms of the projects. It is very efficient, but there is not enough integration with the other stages of the project.

How is the team workflow organized?: For many, knowledge and communication is fundamental in order to have a good team workflow. Usually iterative processes must be performed between different stakeholders involved, such as the planning offices, the architecture firms designing the project and the microclimate consultancy. Jana Caase, as Environmental Scientist working in consultancy projects, explains that "one or two people in the Office are responsible for one project from beginning to end to get to know the clients" (J. Caase, video interview, March 25, 2021). This enhances a clear communication channel along the entire process and areas. From the perspective of Anterola, engaged in projects from an integrative perspective beyond consultancy, he explains the workflow dynamic as "an iterative process requiring multiple parties to be involved at various stages. Keep in mind that the varying interests will not necessarily align and thus, while a smaller team of experts may use the actual simulation tools, often, there are others who are responsible for engaging with multiple stakeholders" (J. Anterola, video interview, March 18, 2021). This sets a significant difference between the approach assumed by a consultancy and by a planning office.

4.4.3. In regards to the hurdles found during the simulation process.

A recurrent challenge was mentioned when referring to the process of performing simulations and it is regarding how time-consuming the computer simulations are. This, of course directly relates to the complex physical model that must be designed for these type of software to comprehend the amount of factors affecting microclimate. Up to now, the existing computer power cannot deliver results in a faster way and this time dedication is one of the most significant hurdles for the planning processes. This is specially cumbersome when a client requests quick answers.

A second challenge which derives from this first point is also related to the computer power. In this case, it can be limiting how much area can be covered and how large the model can be for a proper microclimate simulation. There is an important calibration which should be made between the scale of what shall be assessed, and the area covered, in order to guarantee that all physical phenomena relevant for the urban environment are considered. It is not the same to model and simulate a street canyon, than an entire city center, and this might be still a limitation for some microclimate computer tools.

Another aspect which demands dedication is the selection of the appropriate input data. This, is not an automated process, it is human-driven, many decisions should be taken at this point, and the reliability of the selected data will greatly affect the outcome of the results. Caase, for example, states that “this is one of the parts of the process that often takes the longest time, to get all the necessary input data” (J. Caase, video interview, March 25, 2021). Input data refers both to aspects needed for the modelling phase _such as the materials selected, proper geometry of the urban form, vegetation location and type_ but also to the meteorological data which will be further used for the simulation phase, and whether this data is general or site specific, statistical or historical data.

Finally, a microclimate study executed on one building _perhaps for energy performance purposes_ and that of a city section _for outdoor thermal comfort, for example_ are of two different situations and are affected differently by its variables as well. Assessing the outdoor environment involves many more complex and dynamic variables, like seasons, and should be questioned if perhaps this is one of the reasons it is not incorporated more often into the city planning process.

4.4.4. In regards to the output resulting from the simulation process.

Expectation of results: Once the simulation output is obtained, results must be interpreted. This is not an automated process done by the software, but a human activity. So, it can be said that human interpretation and representation of the results is still an indispensable part of the process, and that digital tools are not entirely responsible for the outcome obtained. Naboni explains how “simulations tend to underestimate what is going on in reality, but it shows the trend (…) we should not look at the numbers we read, but we should read the tendency, otherwise the simulation may tend to not offer insightful information” (E. Naboni, video interview, March 18, 2021). In this sense, simulations should be understood as an approximation to reality and not reality itself. Furthermore, when discussing with Prof. Udo Dietrich the output results, he considers “the results can only be as good as the input values, if they have been precisely the right ones, and there is uncertainty (…) there is a certain risk and it is needed a bit of experience or skeptical view to see the results or the procedure" (U. Dietrich, video interview, March 18, 2021). So, in order to analyze efficiently the obtained output from the software, expertise, strong interpretation skills and skepticism to detect unreliable results are needed.

What is the target? What is assessed?: Once again, depending on the approach of each expert consulted, the usual target addressed can be varied. The most relevant objectives for a microclimate assessment focus on Urban Heat Island, Energy Performance, Climate Adaptation, Outdoor Thermal Comfort, Pollution and Health. What is agreed upon by many is the fact that there is a growing interest in recent years to assess microclimate in urban contexts, "more and more cities would like to know more about their climate situation" (J. Caase, video interview, March 25, 2021) explained when discussing how often is this type of study requested. Nevertheless, a more holistic view of the ecosystems for future assessments is also recommended by Naboni, "one of the problems today's planning is that it is thinking too human centric (…) we must think regenerative and add value to other species" (E. Naboni, video interview, March 18, 2021).

Level of precision of the results: As previously stated, many experts agreed that up to now a simulation will not be as precise as reality, but this should not be the expected intention. Imprecision should be accepted as part of the outcome, but the approach should be to focus on learning from the trend of the output, with a broader perspective. Anterola clearly notes the different approaches depending on what is expected as results, "when working with early stage masterplans or conceptual design solutions, our goal is to provide firstly an orientation and overall direction, where an iterative planning process relies on working quickly to test multiple solutions that are less precise but guide decision-making. As planning becomes more detailed, so too must the assessment tools used to validate and optimize solutions" (J. Anterola, video interview, March 18, 2021).

4.4.5. In regards to the representation of the results.

Translating, decoding and the use of additional tools: In most cases, the end-user of this information will not be a microclimate expert, but still a relevant actor within the overall process. Therefore, the content should be de-coded, "it is needed to make a translation from the science knowledge, to recommendations to planning. They are really different languages" (L. Katzschner, phone interview, March 19, 2021). The challenge is then how to simplify the content properly. It was an unanimous statement, that other tools are further incorporated into the result-delivery process, beyond the microclimate computational tool. For some, this can be simple excel graphics, for other more complex plug-ins related to 3D software such as Grasshopper are used. The use of 3D visuals is considered a useful resource to explain the output to non-expert stakeholders, explained Jana Caase who, coming from an environmental science background, also commented the usefulness of interdisciplinarity for the assessments "as we are often involved in planning processes, it is useful to have city planning or architectural knowledge as well" (J. Caase, video interview, March 25, 2021).

4.4.6. In regards to the communication of the results.

The non-computational process of communicating the results requires the fine skill of simplifying the content without leaving out relevant parameters or as mentioned by Naboni "Simplicity and clarity is important (…) the result does not have an impact if it is not simplified but without being banalized" (E. Naboni, video interview, March 18, 2021). It is a completely human step, and can be assumed as a teaching process for the receiver of the information. For Anterola, this stage of the assessment is one of the most challenging, because communicating properly the output can be understood as a chain of actions among the different stakeholders involved, and the content must be clear enough to travel safely without losing valuable information or breaking the chain of communication. This refers, of course, to the decision-making phase of a planning process, and many times the microclimate consultant passes on the information in the form of a report, but does not communicate further with the subsequent actors involved. Another relevant objective of good communication of the output, is that consensus should be achieved in order to make successful decisions, "city planning today is often a highly technical, resource-intensive and complex process involving a broad group of stakeholders where microclimate simulations are an important yet singular aspect of an overall project. Aligning decision-makers from both a top-down and bottom-up perspective - including citizens - early on has the potential to stimulate consensus and enable informed planning" (J. Anterola, video interview, March 18, 2021).

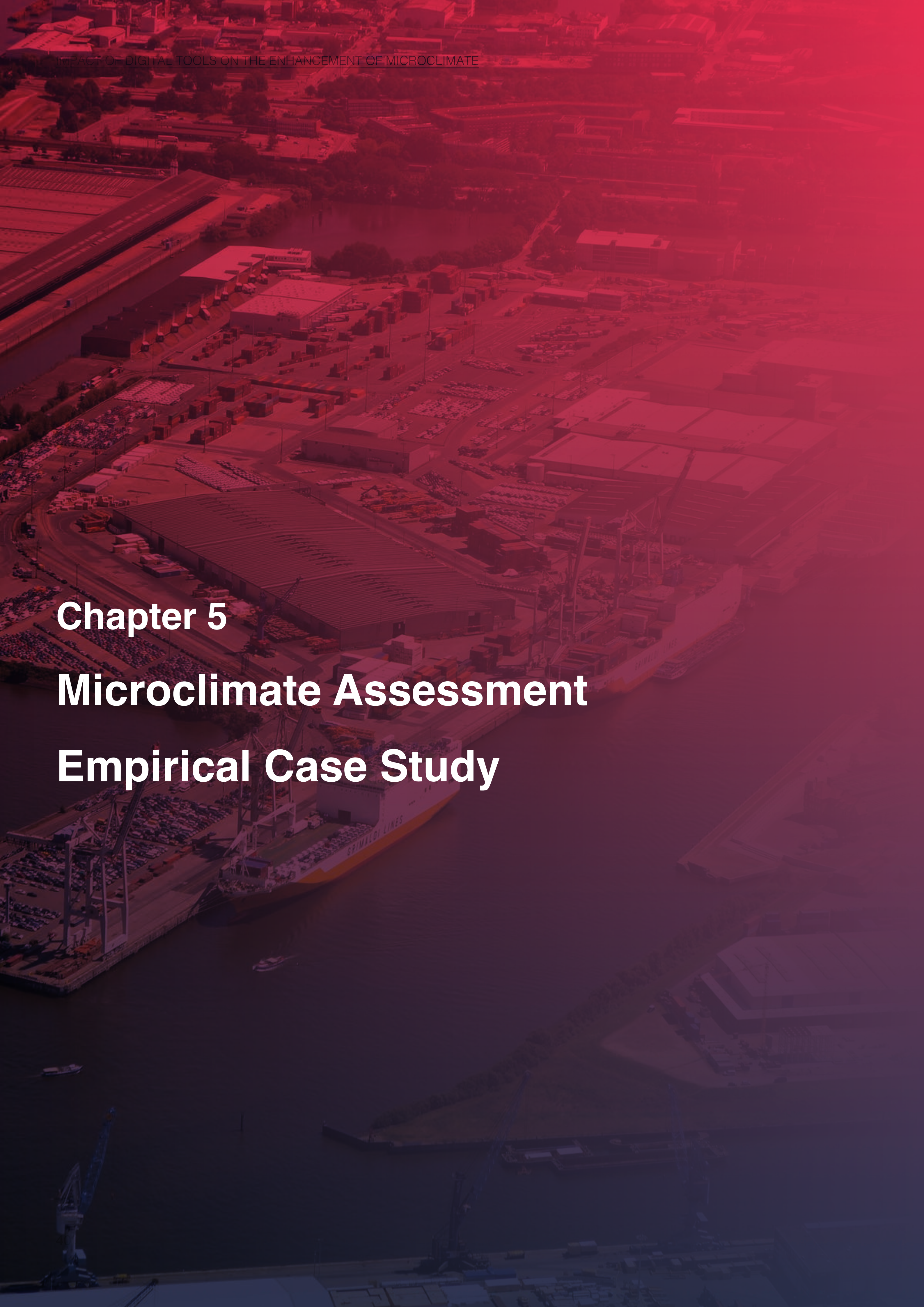
4.4.7. In regards to understanding the end-user or client for the endeavor.

As mentioned previously, the end-user of a microclimate assessment, is usually the person or institution who requests such an endeavor from the start. In this sense, the end-user or client can come from diverse fields related to design, assessment or guidelines and regulatory purposes. A common ground understood along all interviews, is that usually the end-user can be a non-expert on microclimate topics, but is the one who determines many of the general aspects on this type of assessment, such as pointing out the goal of the task, setting the pace or time-frame for the assessment, and ultimately making the final decisions. Communication with the end-user is therefore necessary from beginning to end of the process.

4.4.8. In regards to future development opportunities for microclimate assessment.

Towards the end of the interview sessions with each expert, many topics emerged regarding space for microclimate development. From the technical perspective, improvement in software for faster calculation time is unanimously demanded. There are also specific parameters which demand further research to understand their impact on the microclimate, Anterola mentions for example the role of evapotranspiration and green facades, or the exchange between indoor and outdoor environments in urban centers is something also suggested by Caase and Naboni.

When referring to the topic of input data, more complete city measurements would allow the analysis of urban regions in need of this type of assessment, so the availability and reliability of data is important, according to Katzschner. Part of the necessary data which is not yet widely available is health data, Naboni stresses the importance of “plugging more domains into the microclimatic discourse and work with public health data” (E. Naboni, video interview, March 18, 2021). A strong effect on microclimate is related to urban health and particles in the environment. In view of climate adaptation measures, also more future scenarios should be simulated and analyzed. A closing remark regarding future opportunities, came from the discussion with Dr. Emanuele Naboni, where he states that the scope in which microclimate is being understood should be broadened, and create co-development among different ecosystems beyond only the human ecosystem, to guarantee a sustainable environment in the global sense. “It is about creating a zoning, with conditions that hosts much more than only humans. I think the sustainable paradigm is obsolete, and we have to use regenerative approaches. We have to stop thinking human-centric” (E. Naboni, video interview, March 18, 2021).



Chapter 5

Microclimate Assessment

Empirical Case Study

5.1. Definition of the Case Study: New Grasbrook District Development in Hamburg.

5.1.1. Relevance of Grasbrook as a Case Study.

The Grasbrook Quarter is located in the Free and Hanseatic City of Hamburg. It is one of the four quarters conforming the island between the course of the North and South Elbe River (Figure 13). The city of Hamburg is known as one of northern Europe's most important Port cities, with a direct access flow from the North Sea; and due to this, Grasbrook has been historically destined to have predominantly port-related activities, thanks to its direct accessibility from the river banks.

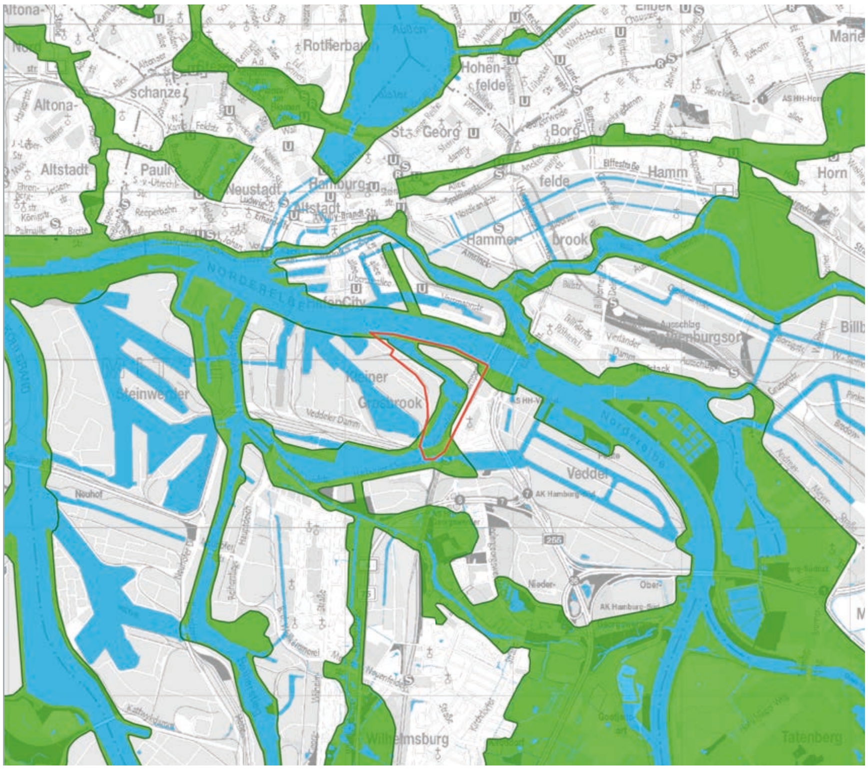


Figure 13. Riverbanks on the Norderelbe and Elbinsel, Grasbrook Quarter marked in red.
Note: From *Brief for a Competitive Dialogue compliant to Article 18 VgV for an urban design parameter plan "Funktionsplan" and a landscape design scheme "Freiraumplanung" Grasbrook District in Hamburg,* by HafenCity Hamburg GmbH, 2019. p.47. Copyrights 2019 by HafenCity Hamburg GmbH.

Nevertheless, in recent decades, Hamburg's population and employment growth has demanded the development of new urbanization to accommodate more residential and civic land-use (HafenCity Hamburg GmbH, 2019). The strategic location of Grasbrook in the central District of Hamburg-Mitte (Figure 14), kickstarted the transformation plan of this area into a potential new residential District of its own, also because of its possibilities to develop further the North-South connections of the Hamburg metropolitan area. This urban regeneration plan is carried out through an open competition by Hafencity Hamburg GmbH, a city-owned corporation in charge of urban development with an integrative and sustainable approach (HafenCity Hamburg GmbH – Integrated Development Management, n.d.).

Figure 12 (opposite page). Aerial view of Grasbrook, showing its Port activity.
Note: From *Brief for a Competitive Dialogue compliant to Article 18 VgV for an urban design parameter plan "Funktionsplan" and a landscape design scheme "Freiraumplanung" Grasbrook District in Hamburg,* by HafenCity Hamburg GmbH, 2019. p.49. Copyrights 2019 by HafenCity Hamburg GmbH.

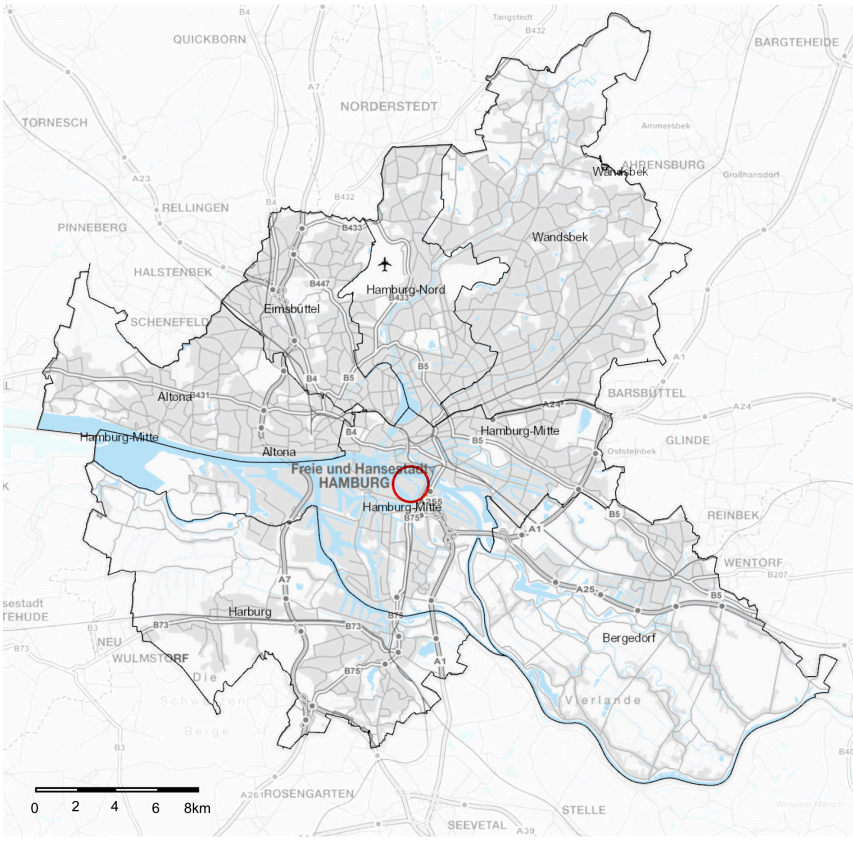


Figure 14. Location of Grasbrook within the District of Hamburg Mitte.
Note: Adapted from *geoportal-hamburg.de*, by Landesbetrieb Geoinformation und Vermessung [LGV], n.d. Open Source.

The relevance of the new Grasbrook District to be considered as a case study for an explorative microclimate assessment comes mainly from the interest in engaging with an unbuilt urban proposal, which additionally holds within its development process, a collaborative study towards innovative measures for city planning. The objective behind the collaboration between Hafencity Hamburg GmbH as promoter, and the City Science Group at the MIT Media Lab and the Digital City Science (DCS) at Hafencity University as research groups, is to revolutionize the traditional methods for city planning, in this case for competitions, by incorporating within the decision-making process the use of data as an advantage to visualize in a more efficient way the overlapping situations affecting the impact of urban development. "The common denominator of this partnership is the idea of a scientific, evidence-based approach to urban development that exploits all possibilities of state-of-the-art digital technology and data analysis" (López Baeza et al., 2021, p.2). Understanding how microclimate digital assessment can be further applicable from this perspective, gives this study the possibility to contribute to future urban regeneration methods for other districts in the German or European context.

5.1.2. Overview of the planning process for the Grasbrook Competition.

For the purpose of developing the new Grasbrook District, the process for an international public competition began in 2018, with a strong public participation approach. The first outcome was the generation of a legal document setting the standards and conditions to select a winning proposal, this is the Competitive Dialog Design Brief. The promotion and execution of the competition is under the shared responsibility of Hafencity Hamburg GmbH as the urban development company, in consultation with the city of Hamburg, which is represented by the Ministry of Urban Development and Housing and the Ministry of Environment and Energy (HafenCity Hamburg GmbH, 2019)

One of the most innovative aspects of the Grasbrook Competition was the equal importance given both to the urban and landscape proposals. In this sense, the landscape considerations for the new District is understood not merely as greenery, but as an intrinsical part of the urban solution for sustainable development and preservation of the ecosystems. (HafenCity Hamburg GmbH, 2020).

In April 2020, the joint firmas Herzog & de Meuron Basel LTD and Vogt Landschaftsarchitekten AG were selected as the winners of the Grasbrook Competition, holding the most adequate solution in terms of both urban and landscape design considerations respectively (see Figure 15).

Figure 15. [Rendering of winning urban proposal for the new Grasbrook District, by Herzog and de Meuron Basel LTD].
Note: From *1. Rang – Grasbrook Hamburg,* by HafenCity Hamburg GmbH, 2021.
Copyright 2021 by HafenCity Hamburg GmbH.

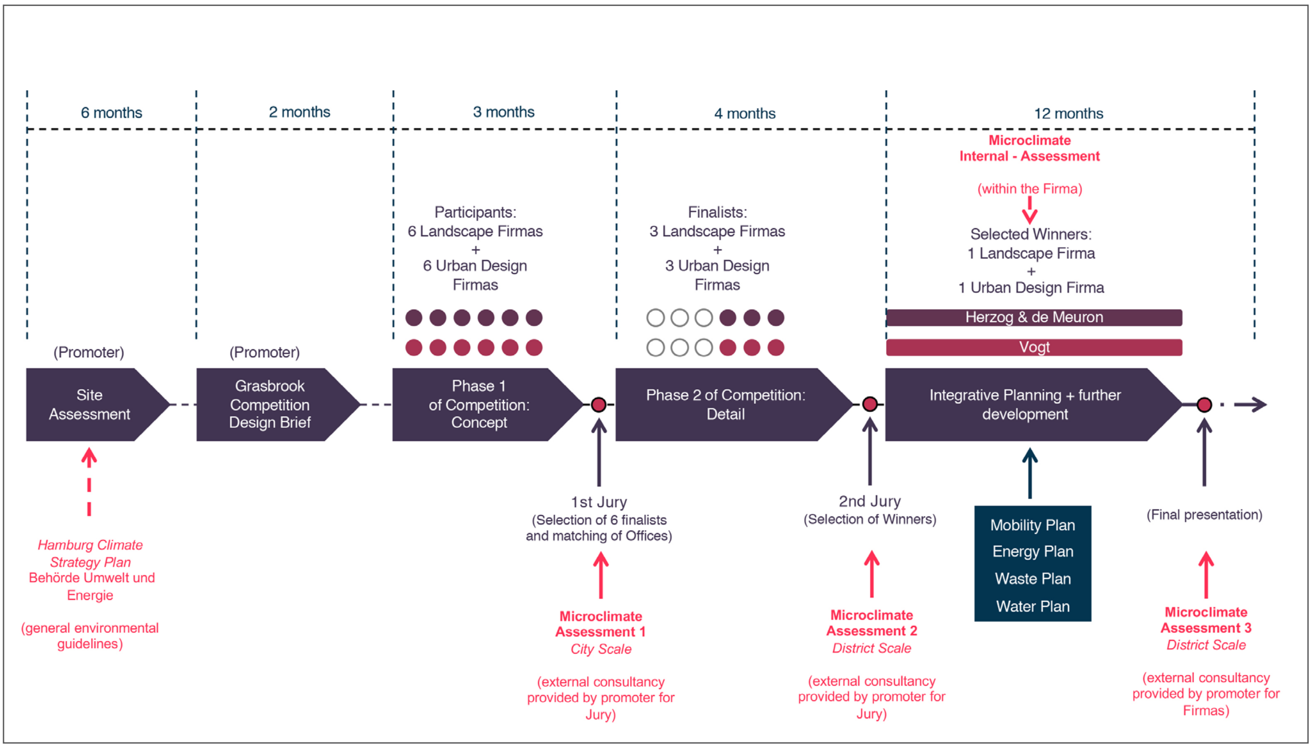
5.1.3. Status Quo of the Grasbrook proposal.

Once the Competition procedure has filtered out the Concept and Detail Phase, and after the selection of the winning proposal, it is currently undergoing the development of the Integrative Planning, with expected construction beginning in 2023, according to the competition website (HafenCity Hamburg GmbH, 2020).

Along the process of the Concept, Detail and Integrative Planning for Grasbrook, several expert consultations were made for technical assessment of the environmental aspects affected by the selected proposal (Figure 16). Within these consultations, microclimate was one of the relevant topics, especially in terms of wind and radiation affectation.

As explained by Philipp Preuner, working in Hafencity Hamburg GmbH, in matters related to Urban Sustainability and Innovation at District Scale, the purpose of the microclimate assessments during the first phase of the competition, was to perform a check-up for any critical spots in the proposals, especially in reference to areas of heat and wind distress in open spaces. These assessments had a double purpose, to serve as a guide for the designers, and also as an evaluation tool for the Jury to reach a decision. For the second phase of the competition, the assessments were of aid to provide the competitors with a series of guidelines now established by the Jury, which were to be fulfilled by the winning team (P.Preuner, video interview, May 17, 2021).

Figure 16. Timeline of the Grasbrook Competition (author 2021). Note: Adapted from *video interview*, by P.Preuner, May 17, 2021.



Besides the mentioned consultancy assessments, the Digital City Science Group (DCS) as one of the research branches of the explorative collaboration for the development of the competition procedures, was of additional support through their innovative online platform, the Cityscope, which served the purpose of simplifying decision-making processes of the competition for both the competitors and the jury. As explained by López Baeza et al. (2021, p.6), "the CityScope is designed to become a holistic platform comprising a broad range of modules for the analysis and simulation of urban key parameters as well as for the complex interactions of physical and social environments". This is achieved through the design of a front-end interface which enhances more interaction among different actors involved, and it is supported by a series of back-end modules, each referring to specific urban parameters of the Grasbrook case. The definition of the first analytical modules to be implemented were agreed upon by the promoter and the research group according to relevance, testing in this case parameters related to noise, stormwater, walkability and gross-floor area. Currently, new modules are being developed for future assessments, one of them destined for the analysis of local microclimate (López Baeza et al., 2021).

5.1.4. Current Climatic conditions of Grasbrook.

Hamburg's general climate conditions are characterized by a Maritime Temperate Climate, according to the Köppen-Geigner climate classification (Kottek et al., 2006). It defines the average climate situation of the city as a warm temperate climate, with fully humid precipitation and warm summer temperatures. The yearly average temperature is 9.8 C, with an average high of 22.6 C in July and an average low of -5 C in February (*Hamburg Climate*, n.d.).

Despite the general conditions of the city of Hamburg, when the specific area of Grasbrook is looked into detail, it is understood that because of its proximity to the water level, and existing impermeable surfaces from the Port activity, it currently holds the effect of Urban Heat Island (Figure 17). As explained in the report by the Ministry of Environment and Energy (Behörde für Umwelt und Energie, 2018) the area of Grasbrook presents a deviation of 3 to 4°C from its average night temperature, due to warming levels in the area. This can be attributed not only to the impermeable surfaces and existing building materials, but also to low wind speed and circulation during summer season.

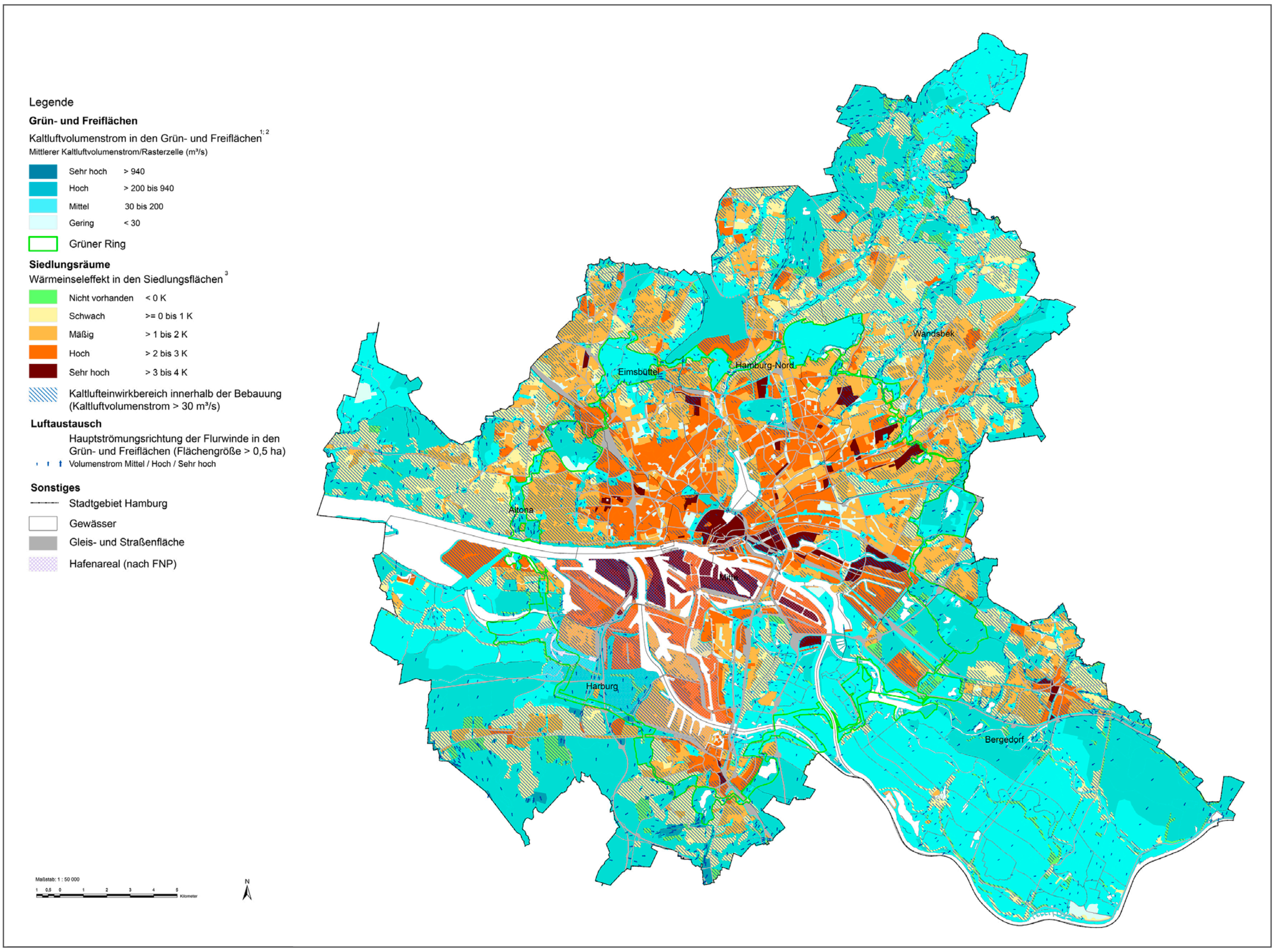


Figure 17. [Map from the Hamburg Climate Analysis 2017]. *Note:* Adapted from *Aktualisierte Stadtklimaanalyse Hamburg 2017,* by Hamburger Stadtportal, n.d.. Copyright by BUE.

5.2. Microclimate Field Measurements

Before performing a digital microclimate assessment through the use of computational tools, on-site measurements were taken. This analog procedure provides beforehand empirical notions of the microclimate conditions of an area such as Grasbrook, as well as a better understanding of the process of analyzing and finding correlations among the gathered climatic data.

Since the proposal of the Case Study is still an unbuilt scenario, the selected area for measurements is the neighbouring District of HafenCity, directly across from Grasbrook, on the northern side of the Elbe. This allows the analysis of a neighborhood with a very similar climatic and geographical situation, since HafenCity is the most recent built-up area, facing the same coastline, over the Elbe and its Canals. In addition, the fact that it is realized by the same developer, HafenCity GmbH, makes it possible to analyze very familiar urban fabric characteristics, such as buildings and surface materials, density, street canyon orientations and types of open spaces (Figure 18).

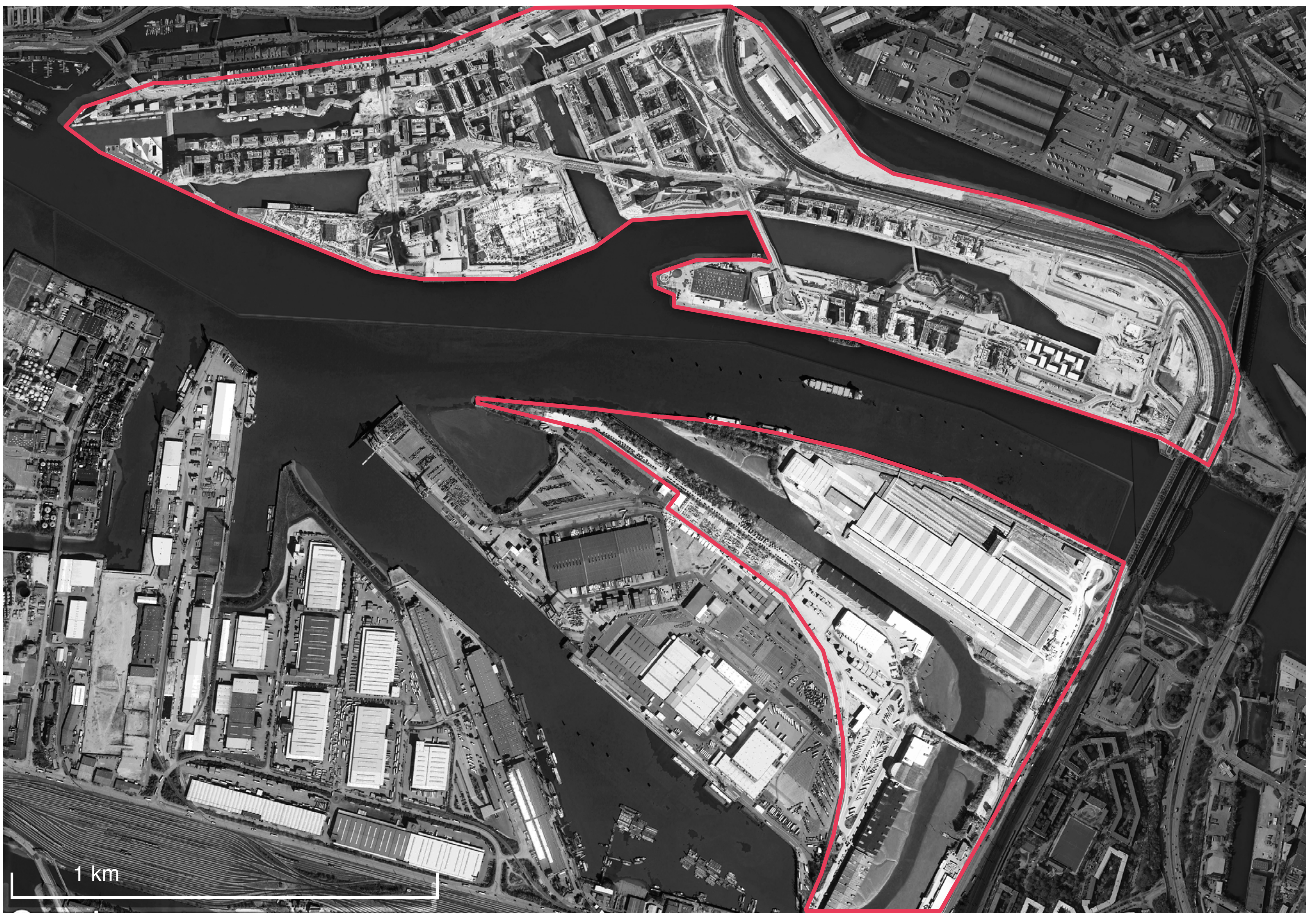


Figure 18. [Aerial view with the Districts of Hafencity, top, and Grasbrook, bottom]
Note: Adapted from *Google*, n.d.

5.2.1. Criteria for Date and Location of Field Measurements.

For the on-site measurements, the date of September 15th, 2020 was selected. It is not the statistical hottest month of the year for Hamburg, but this date presented an unusual peak in temperature, with very few cloud coverage, contributing to a good assessment regarding solar radiation (see Figure 19). In addition, September is the month closest to the average amount of sunlight hours throughout the year. This allows for measurements for an average-daylight situation, instead of extreme scenarios. (*Hamburg Climate*, n.d.).

Within Hafencity, three different open spaces, were selected as locations

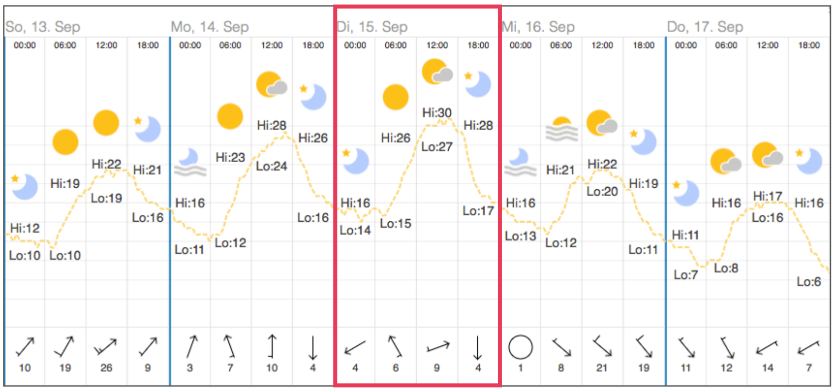
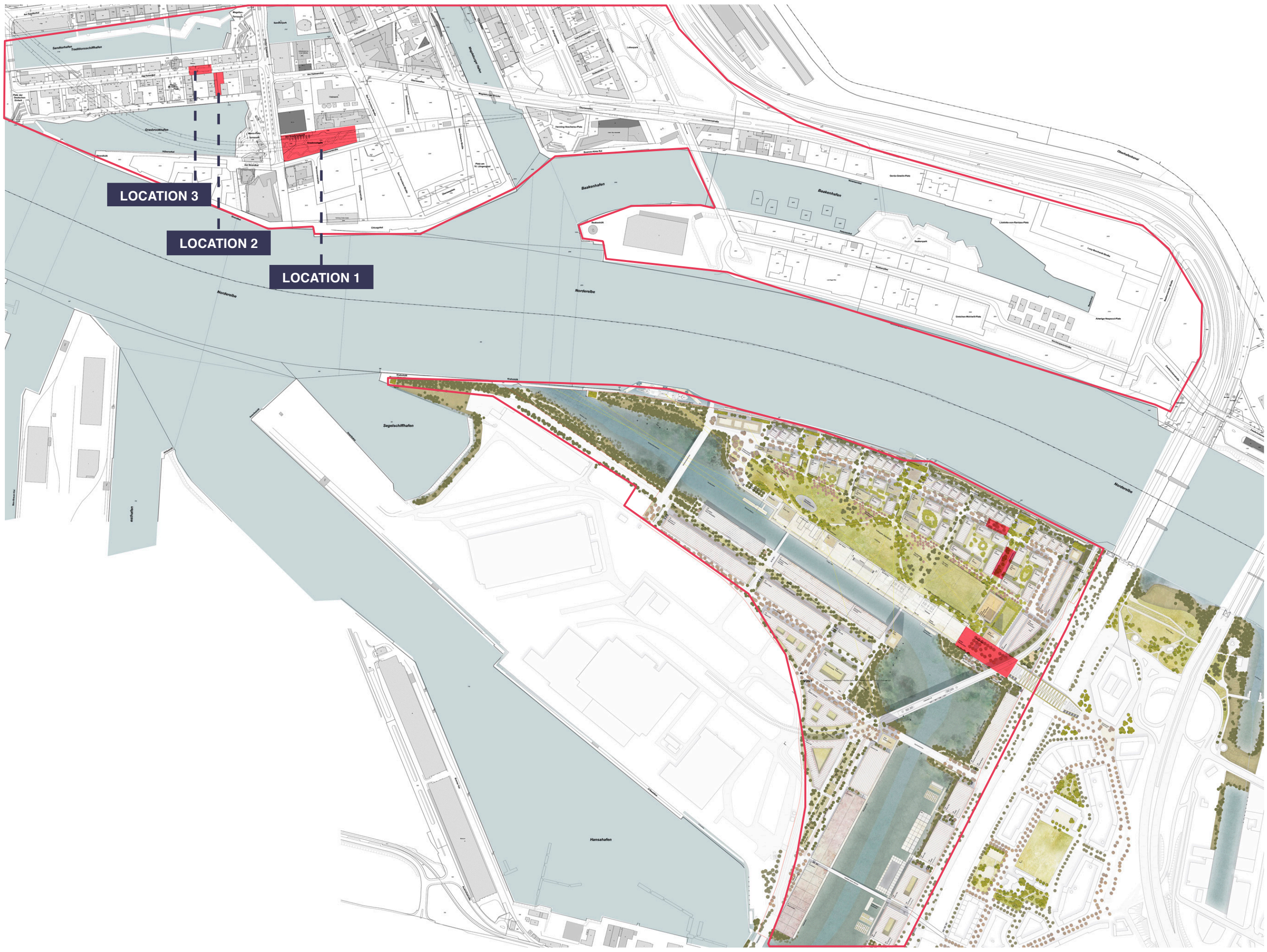


Figure 19. [September 2020 Weather in Hamburg, highlighting the date of measurements].
Note: Adapted from *Weather in September 2020 in Hamburg, Germany, by* Time and Date, n.d. Copyright Time and Date AS 1995-2021.

for field measurements, according to their typology, materials, orientation and area. It was important that these three locations were relatable in form and scale to the types of open spaces proposed for Grasbrook, so the obtained microclimate information could be relevant during the simulation. In Figure 20, the selected locations for measurements can be identified, and seen in comparison to some areas of the proposal.

The first location is Grasbrook Park, a rectangular urban playground area of middle-scale, with a predominantly East-West orientation. The second location is inside a street block over Kaiser Kai, serving the purpose of a pocket square within a residential block, with a predominantly North-South Axis and exclusive for pedestrian use. The third location is directly on Kaiser Kai, a street canyon with an East-West orientation and similar height-width ratio as in the Grasbrook streets proposed (see Figures 23-25). The building density and construction materials for the surrounding buildings and pavements surfaces in all three areas are also similar as those described in the Grasbrook proposal.

Figure 20. [Three measurements locations in Hafencity, comparable to Grasbrook areas, in red]. *Note1:* Vector map, adapted from *ALKIS GDB: Freie und Hansestadt Hamburg* [Map], by Landesbetrieb Geoinformation und Vermessung, 2021.
Note 2: Render, adapted from *1. Rang – Grasbrook Hamburg*, by HafenCity Hamburg GmbH, 2021. Copyright 2021 by HafenCity Hamburg GmbH.



5.2.2. Microclimate Measurement Equipment.

The necessary equipment in Figure 21, used for field measurements was provided by HafenCity University. They consisted of: a Thermal Imaging Infrared (IR) Camera to measure surface temperature of materials at a distance; an Air Velocity Sonde, which measured air temperature, wind speed and relative humidity at pedestrian level; and a Digital Thermometer, for the measurement of surface temperature at reachable distances.

Figure 21. Field measurements instruments: (left) Fluke 975 airmeter, (center) Voltcraft K101 digital hand thermometer, (right) Flir Systems thermal imaging infrared camera (author, 2020).

5.2.3. Methodology for Field Measurements.

The methodology for the measurements was based on previous research from the Master Thesis by Henríquez and Milenkovic (2016). A set of pre-assembled Excel tables (Annex B1-B3) were carried on-site and filled out with climate data taken through the use of the equipment, and compared to values from the Deutscher Wetterdienst (www.dwd.de) mobile app (Figure 22).

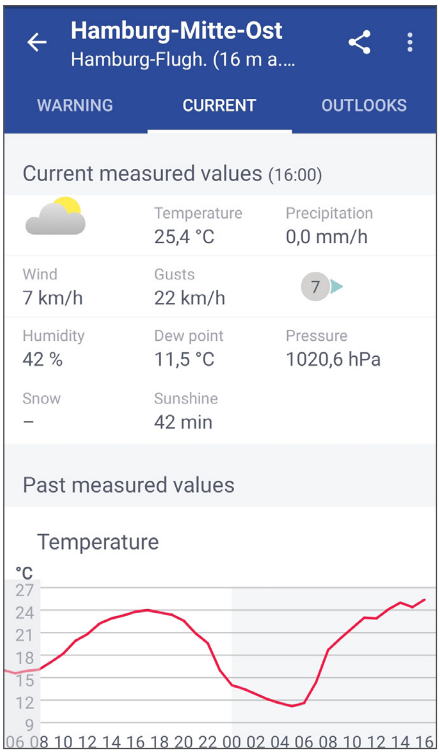
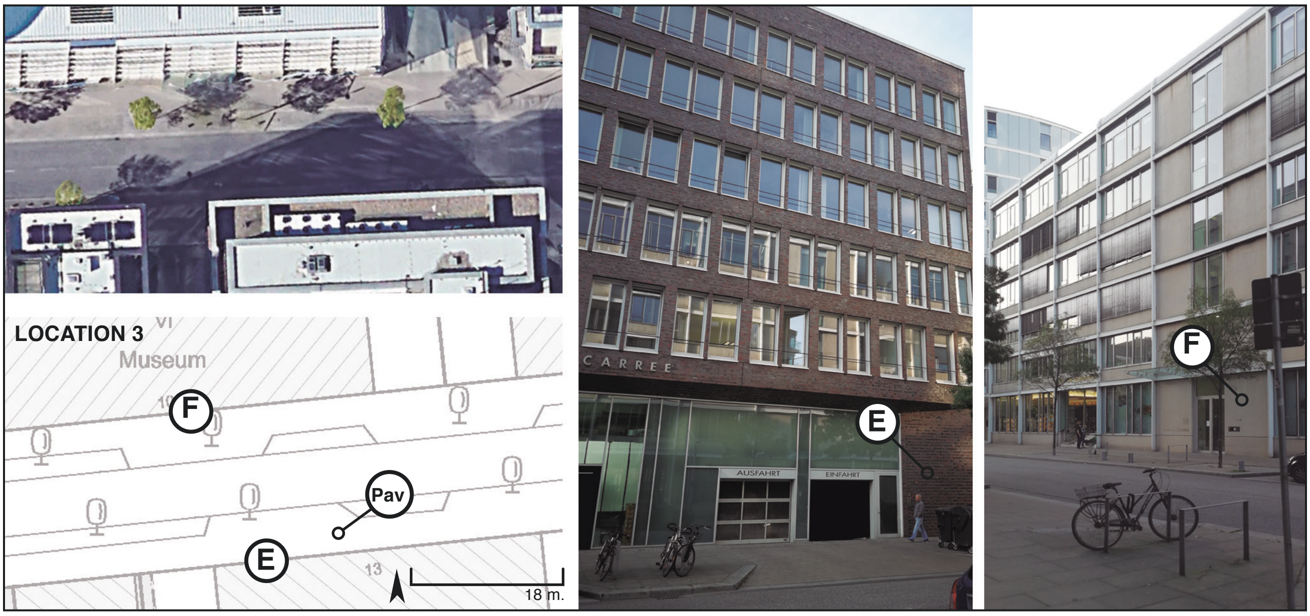


Figure 22. [Sample screenshot of the measured values provided hourly by the DWD mobile app].
Note: From *Warnwetter* [mobile app], by Deutscher Wetterdienst, 2020.


LOCATION 1
A
B
Pav
2368
Am Grasbrookpark
2370
Grasbrookpark
56 m.


LOCATION 2
D
Pav
C
VIII / -I
19 m.


LOCATION 3
Museum
F
Pav
E
18 m.
AUSFAHRT
EINFAHRT

In each location, 2 facades points and 1 pavement surface point were selected for the repetitive measurements (Figures 23-25). The measurements taken consisted primarily of relative humidity, air temperature and wind speed, taken at 16 meters height and extracted from the DWD mobile app; at the same moment, same values were measured on site, at 1,5 meters height with the corresponding equipment. Additional data was gathered, only on site, corresponding to surface temperature of facades and pavements, direct or indirect solar radiation on surface, and cloud coverage. In order to obtain corresponding values along the entire period, equal distance against each façade must be kept; therefore tape marks were left on the floor in front of each location. This distance is measured once and set as input for the infrared camera. Also, the direct surface temperature measurements should be made in the same spot hourly, so the same method of tape marking was used. Hourly measurements were taken along a period 14 and a half hours, from 06:50 am to 09:20 pm., over all three locations. A longer period was not sought after, because the surface and air temperature taken at the last measurement round, in all cases, had already surpassed its peak and had begun its descent. In Annex B, the tables corresponding to the entire data gathered can be read in further detail.

Some limitations during the field measurements should be mentioned in this chapter, before explaining the outcome of the on-site assessment. Due to time-bound difficulties on site, some measurements at the specific timeslots were not able to be taken. In this case the space on the table is left empty, to make sure it does not alter average values. During the calibration of the material emissivity factor on the IT Camera, for the measurement of the dark metal and glass façade, the value was set to 90 when it should have been at 15 (Envi-Met Company, 2019), therefore the thermal measurements with the IR camera should be disregarded for the data on façade point B. Finally, the wind speed data in the DWD mobile app is registered in km/h and was therefore converted to m/s to relate the values to the rest of the study.

Figure 23 (opposite page, top). Location 1, at Grasbrook Park, indicating points measured.
Note 1: own photos.
Note 2: Aerial views, adapted from *Google*, n.d.
Note 3: Vector map, adapted from *ALKIS GDB: Freie und Hansestadt Hamburg* [Map], by Landesbetrieb Geoinformation und Vermessung, 2021.

Figure 24 (opposite page, center). Location 2, pocket square over Kaiser Kai, North-South oriented, indicating points measured.
Note 1: own photos.
Note 2: Aerial views, adapted from *Google*, n.d.
Note 3: Vector map, adapted from *ALKIS GDB: Freie und Hansestadt Hamburg* [Map], by Landesbetrieb Geoinformation und Vermessung, 2021.

Figure 25 (opposite page, bottom). Location 3, street canyon at Kaiser Kai, East-West oriented, indicating points measured.
Note 1: own photos.
Note 2: Aerial views, adapted from *Google*, n.d.
Note 3: Vector map, adapted from *ALKIS GDB: Freie und Hansestadt Hamburg* [Map], by Landesbetrieb Geoinformation und Vermessung, 2021.

5.2.4. Outcome of the Field Measurements.

Air Temperature, Wind Flow and Humidity.

The results obtained from the field measurements task, revealed that in fact the air temperature registered among all three locations, showed a mean value of 1,4°C higher along the entire day, in comparison to that from the DWD weather station. An important factor to consider in this case is the location and height difference between the measurements at the weather station located at the Hamburg Airport, corresponding to the DWD data, and the specific location of the site measurements in HafenCity, closer to the water body of the Elbe. Nevertheless, it can also be related to the fabric of the urban form in the measured neighborhood.

When the air temperature difference between the DWD app and the onsite data is compared, individual assessments were also done for each measured location. In the Grasbrook Park (location 1), the average temperature difference between app and on-site was 2,5°C higher on site than in the app; much higher than in the other two measured areas, where the differences was 0,96°C (location 2) and 0,80°C (location 3). This can be related to more hours of direct SWR on the first case, versus more areas under shade on the other two locations; as it can be seen in the complete data from Annex B. From the entire registered air temperature measurements, the highest value was noted in location 1, at 4:17 pm, reaching 32°C, which is considered a moderate heat stress level for outdoor thermal comfort, according to the PET scale Index (Table 01, p.24).

In regards to the wind assessment along the day, the measured values on site are never above 2 m/s, which corresponds to the usual wind conditions during Summer days in Hamburg. The mean difference of the wind speed registered on all 3 cases maintains itself within a range of 1,2 to 1,8 m/s higher in the DWD app at 16 meters, from that measured on site at 2 meters. This lower wind speed at pedestrian level in HafenCity can be caused by existing obstacles within the city grid, thus affecting the incidence on pedestrians.

The relative humidity conditions in the three measured areas, show a clear variation between the registered values by the DWD and the data from the field work, with higher relative humidity levels at the DWD weather station. The ranges however, are varied in each case, when compared in detail. Nevertheless, a constant tendency shows that towards the early morning or the evening the difference between both measurements is greater, while near the middle of the day, when the temperature is higher, the relative humidity level difference is minor.

A general observation on the microclimate conditions of all three locations, was the inverse fluctuation between relative humidity and air temperature values along the day. As the air temperature increased, the relative humidity decreased, and vice versa (Table 05). This simply evidenced the existing direct correlation of different atmospheric factors, which are relevant to understand the dynamics behind outdoor thermal comfort.

LOCATION 1 Rel. Humid. (%) at 1.5m.	LOCATION 1 Air Temp. (°C) at 1.5m.	LOCATION 2 Rel. Humid. (%) at 1.5m.	LOCATION 2 Air Temp. (°C) at 1.5m.	LOCATION 3 Rel. Humid. (%) at 1.5m.	LOCATION 3 Air Temp. (°C) at 1.5m.
78,4	16,5	76	16,9	73	18,1
66,3	20,1	66,1	20	64,2	20,9
60,6	22,7	61,3	22,6	61	22,7
53,3	25,9	57,5	24,6	56,8	25
45,5	29,2	48,2	28,2	50,1	27,4
43,4	30,2	45,6	29,3	47,3	28,9
43,3	31,7	48,1	29	46,1	30
42,9	32	47,3	29,3	48,4	28,6
41,8	31,5	47,1	28,1	44,8	28
44,1	29	48,8	27	49,7	26,7
53,2	26,1	54,4	25,5	56,3	24,9
56,9	25	62,3	23,6	61,4	23,6

Table 05. Inverse fluctuation of temperature and humidity among the three measured locations (author, 2021).

Surface Temperature of assessed Materials.

For the surface temperature of the materials on the selected facades and pavement points, for all three locations, two instruments are used, the digital thermometer and the thermal IR camera. The purpose of this is to compare the results of both measurement methods. Also, the IR camera provides the possibility of measuring remotely, and thus raising surface temperature data of higher points in the facades which would otherwise be unattainable. For location 2 and 3, the compared temperature measurements, taken with the digital thermometer and the IR Camera, resulted in a mean value difference of +/- 0,1°C, which is not a significant difference. For location 1, however, the value difference is much higher. This margin error could be related to calibration issues of the IR camera, or because it is the location where higher direct SWR was received on the facades along most of the measured day, comparable on Table 06. To guarantee higher reliability of the results, the surface measurements through the IR Camera were disregarded, and only the digital thermometer surface measurements at pedestrian level are considered in all cases for comparative purposes.

LOCATION 1		LOCATION 2			LOCATION 3		
	Fac. A		Fac. C	Fac. D		Fac. E	Fac. F
HOUR	DARK BRICK	HOUR	DARK BRICK	WHITE PLASTER	HOUR	DARK BRICK	WHITE PLASTER
	Direct Sun Y/N		Direct Sun Y/N	Direct Sun Y/N		Direct Sun Y/N	Direct Sun Y/N
6:55	N	7:50	N	N	8:28	N	N
9:05	Y	9:41	N	N	9:56	N	N
10:29	Y	10:55	N	N	11:09	N	N
11:34	Y	12:02	Y	N	12:18	N	N
12:41	Y	13:09	N	N	13:25	N	Y
13:50	Y	14:18	N	Y	14:32	N	N
15:14	Y	15:40	N	Y	15:54	N	N
16:17	Y	16:41	N	N	16:59	N	Y
17:20	Y	17:43	N	N	17:59	N	Y
18:22	N	18:47	N	N	19:01	N	N
19:23	N	19:47	N	N	20:03	N	N
20:29	N	21:00	N	N	21:19	N	N

Table 06. Comparative table of sun incidence on facade surfaces along the day (author, 2021).

The surface materials assessed are dark brick for facades, located in all three measurement locations; and white plaster for facades, located in two of the three locations. Both of these materials are also suggested in the Grasbrook winning proposal and it is therefore of use to analyze their effect in a similar context. Furthermore, three different types of pavements were also selected for comparative purposes, in this case: asphalt surface light grey, basalt brick stone and concrete pavement medium grey. (Figure 26)

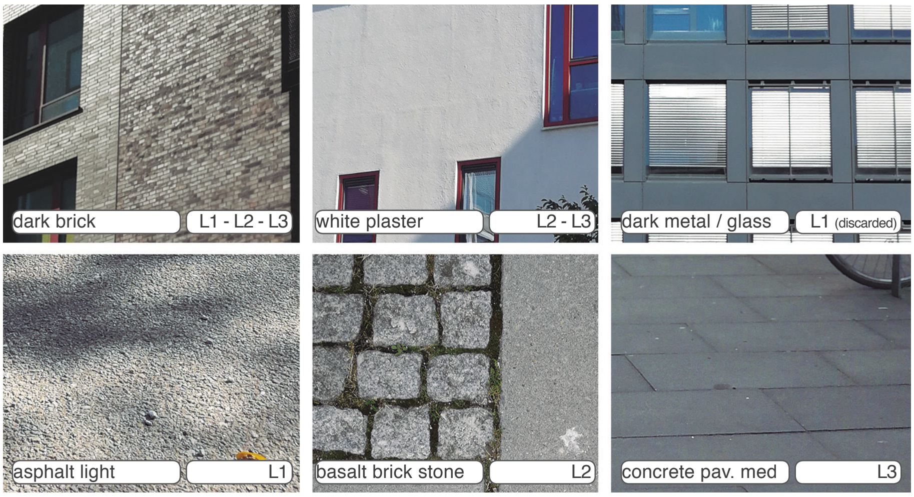


Figure 26. Materials measured across the three locations (own photos, 2020).

In the case of the dark brick for facades, as it can be seen in Figure 27, the temperature variation between façade A and facades C and E is of more than 20°C. This is explained by their orientation, as façade A is frankly oriented South and therefore exposed to more hours of direct solar radiation. The other two cases are facing East (C) and North (E) and receive mostly shade during the measured day. The surface temperature value when exposed to direct SWR evidences the high capability of this material to absorb heat. From the graphic it can be also appreciated how, in the case of Façade A, it quickly begins to cool down after a few hours, even before sunset.

For the analysis of the white plaster for facades, Figure 28 shows a sudden increase of temperature for façade D, facing West during the mid-day, which

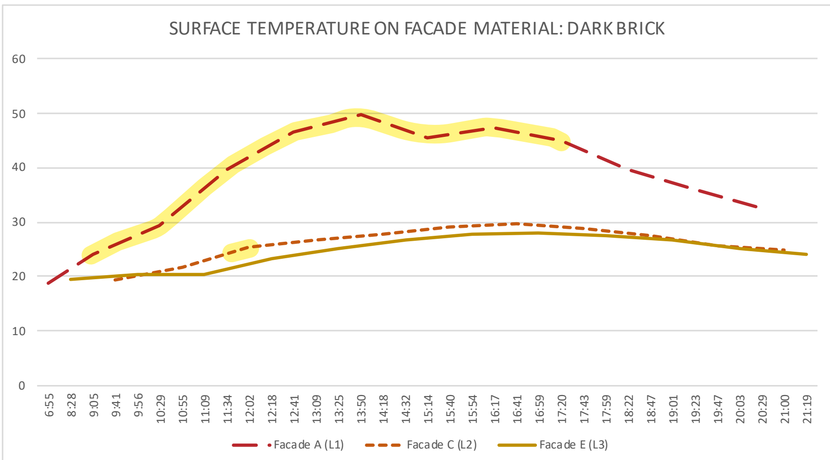


Figure 27. Surface temperature (°C) measured over 14 hours, for three facades with dark brick, hours of direct sunlight marked in light yellow (author, 2021).

is the moment of direct solar radiation hitting the surface. For the façade F, the surface temperature increases in a steady manner without dramatic changes, this can be attributed to the different times when it receives solar radiation, in the case of F it is later in the day when the air temperature is lower. Since the height/width ratio in front of both measured facades is quite similar, the slight difference regarding the behavior of the material in each case can be attributed to the orientation of the street canyons where they are located, along with the direction of the wind flow coming from the West, which would be more favorable for façade F, located in an East-West canyon.

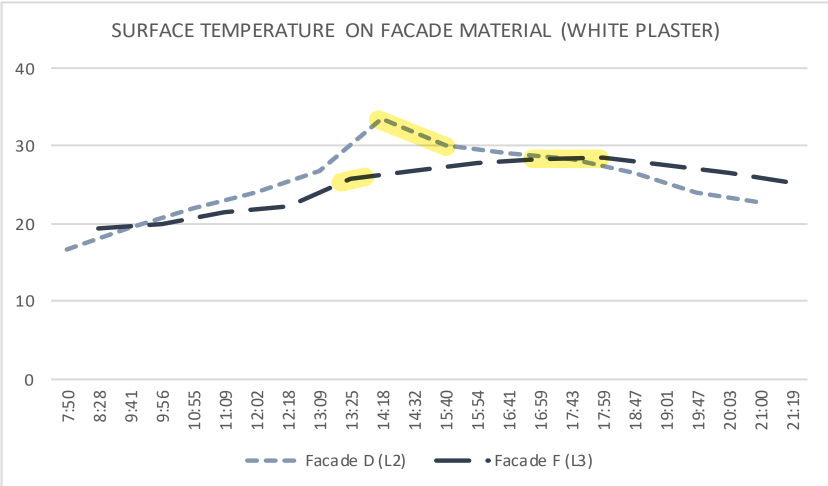


Figure 28. Surface temperature (°C) measured over 13 hours, for two facades with white plaster, hours of direct sunlight marked in light yellow (author, 2021).

In the case of the pavement surfaces compared in Figure 29, a significant difference is seen from the registered temperature increase of the light colored asphalt, compared to the other two materials. In the case of the basalt brick stone, despite a surface temperature rise around the mid-day, the curve shows a favorable temperature reduction under 25°C, aligned with the almost constant temperature of the third material, the concrete pavement medium grey. It can be noted that despite being a day with very few cloud coverage, from the three materials, the asphalt was more exposed to direct SWR, the basalt brick stone was partially exposed at noon, and the concrete pavement was mostly in shade, due to the buildings located around the measured points.

From the gathered results, a series of recommendations for the upcoming computer simulation can be detailed. All materials present significant differences when exposed to direct SWR, so not only the albedo of each material but also the orientation of street canyons as well as the street height/width ratio are determining to achieve spaces with appropriate comfort levels. From the case of location 1, Grasbrook Park, special attention should be paid to south-facing facades when resulting shade from facing buildings is not enough. Nevertheless, dark brick presents good physical properties for heat stress scenarios, thanks to its favorable capacity of absorbing and releasing

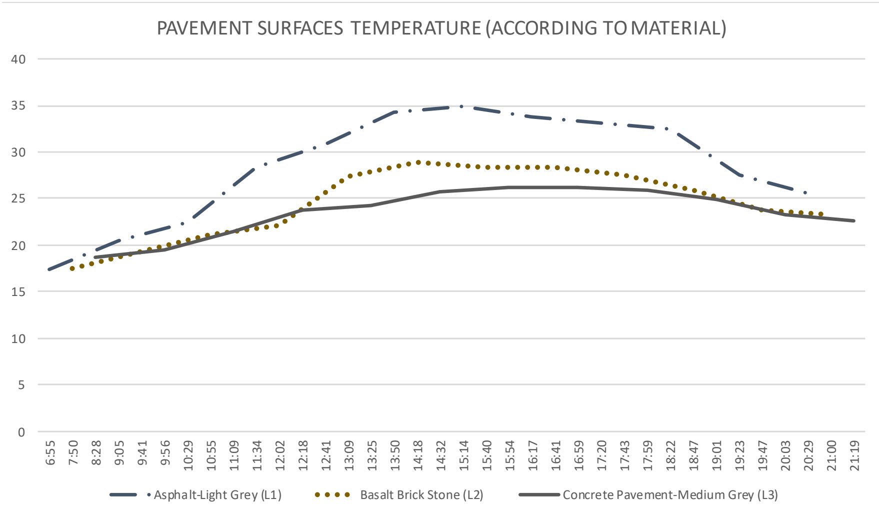


Figure 29. Surface temperature (°C) measured over 14 hours, for three different types of pavements (author, 2021).

heat. For the use of white plaster on facades, the results were favorable but further studies could be done for a scenario with more solar exposure. Among the materials reviewed for pavement surfaces, asphalt should be considered only when necessary, and it is not especially suitable for playground areas. The basalt brick stone showed overall good results and would be a good option for pedestrian pathways. The concrete pavement, medium grey, despite showing favorable results, could be further assessed in scenarios with more solar exposure.

The selected area of HafenCity evidenced a good ratio for the assessed street canyons, when observing the height of buildings in relation to the street width. Understanding that the predominant wind direction in this area is coming from the West, location 3, presented overall more favorable results, compared to location 2, mainly due to its East-West orientation. In this sense, North-South canyons should be paid closer attention to, in regards to the selection of façade materials or the width of the street, to ensure proper shading and diminish the possibilities of heat stress.

Coming back to the previously explained statement by the Ministry of Environment and Energy (BUE, 2018) referring to Grasbrook's current Urban Heat Island effect, the comparable results obtained from the field measurement assessment present a positive outcome which could indicate potential temperature reduction after the urban intervention. The mentioned characteristics of the existing conditions of Grasbrook in regards to impermeable surfaces and building materials typology can easily be overcome by the new proposal, leaving only the issue of low wind circulation to be properly attended by other parameters such as building locations or urban greenery. This can be assessed further in the following step of the proposed methodology.

5.3. Computational Model for Microclimate Simulation

After understanding the microclimatic context of HafenCity through the process of field measurements, one important reflection is the effort it requires to understand the resulted output data, arranged in the form of tables and graphs, and the need to visualize the overlapping phenomena occurring in a more graphic way. In order to complement this experience, a digital assessment of the microclimatic conditions of the Grasbrook proposal is further developed, with the use of a computational simulation software. Despite the broad spectrum of software available for this type of calculation, the selected software to be used is Envi Met Science, version 4.4.5, as previously explained in Chapter 3 of this documentation. As defined by Tsoka et al. (2018, p.57) Envi-Met is "a prognostic, three-dimensional, grid-based microclimate model, designed to simulate complex surface-vegetation-air interactions in the urban environment." It allows for a visual comprehension of the dynamic atmospheric variables overlapping and affecting simultaneously the built environment, through its interactions with buildings, nature and human activity.

The entire microclimate simulation process through the Envi-Met software consists of the following steps: initial setup, digitizing a spatial model of the area to be assessed, running the simulation calculations, processing the output data and finally producing the visualization maps to be analyzed. This is all managed through the Envi-Met Headquarters Dialog Window (Figure 30). The broken-down process will be further explained in detail.

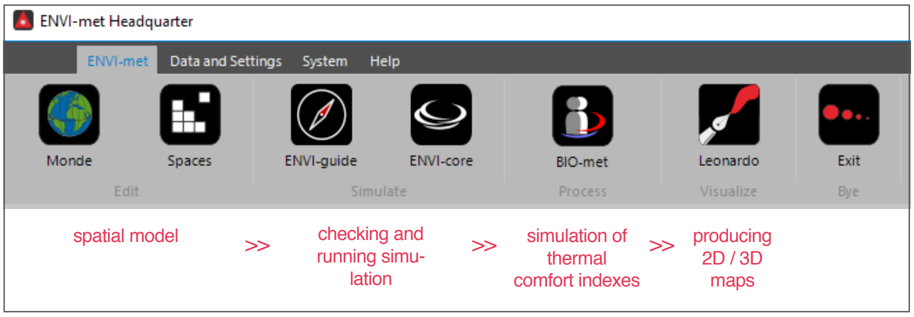


Figure 30. Overview of the Envi-Met Headquarters and subsequent steps for a simulation.
Note: screenshot taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

5.3.1. Initial Setup.

During the initial setup, main parameters such as geographical location and cardinal orientation of the area to be assessed is defined, through the use of coordinates or location name. Also, the model geometry, or the area coverage and scale of the spatial model, is defined, through the amount of grid cells and size in meters per grid cell.

In the case of the model for Grasbrook, the location was defined as Kleiner Grasbrook, Hamburg, Germany, with a rotation of 33 degrees out of grid

North. The entire area of the Grasbrook proposal covers more than 1 kilometer from East to West, which would require a long simulation time and robust computational power. Therefore, the selected area for the simulation (in Figure 31) is limited to a smaller segment of the proposal, which still holds a variety of urban open spaces and heterogeneous building types, enough for a relevant urban microclimate assessment (Figure 32).

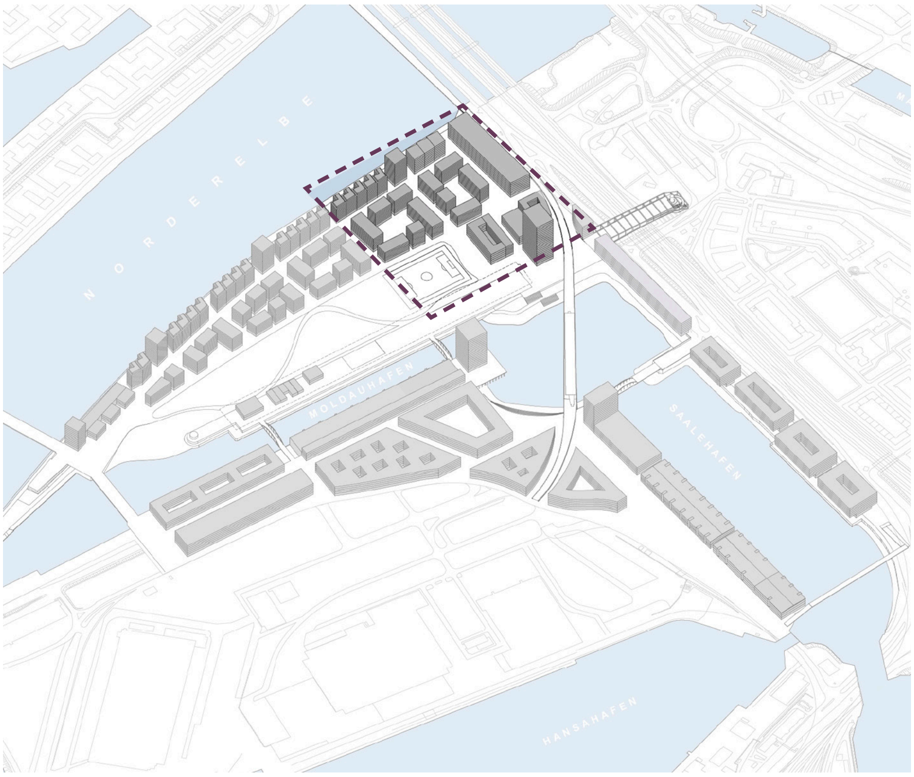
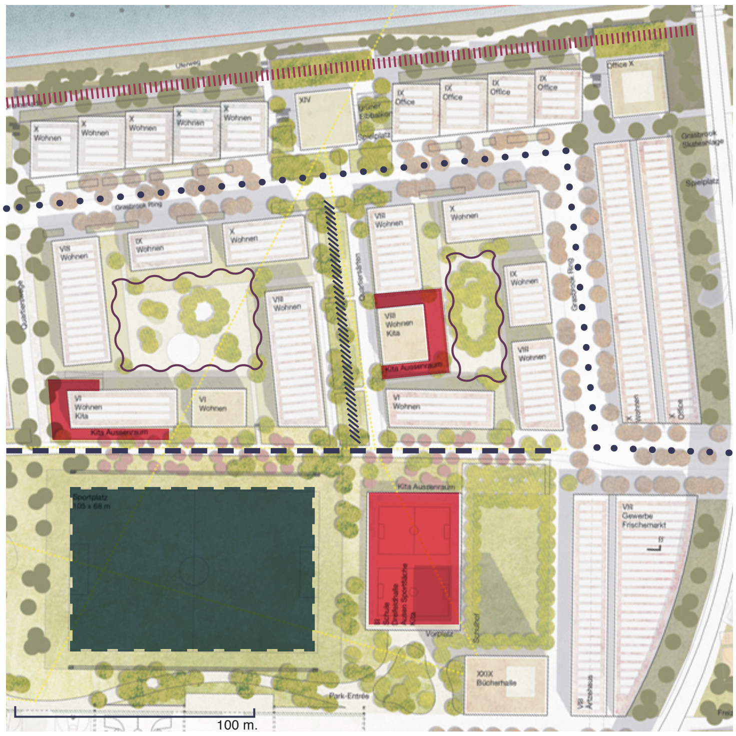


Figure 31. [Axonometric view of the Grasbrook proposal, highlighting the selected area for the study]. *Note:* Adapted from *1. Rang – Grasbrook Hamburg,* by HafenCity Hamburg GmbH, 2021. Copyright 2021 by HafenCity Hamburg GmbH.

In order to define the horizontal scale of detail of the model, the size in meters for the X and Y grid cells is also determined in the preliminary setup. The ideal size of an Envi-Met grid cell should be between 2 and 5 meters, depending on the level of detail needed, and it should be understood that the smaller the grid cell size, the longer the calculation time will be. A two-meter grid cell size is recommended for sufficient detail at a typical District scale. Therefore, the model dimensions were adapted to 151 cells for the X axis and 154 cells for the Y axis, and a cell size of 2 meters is selected, covering a horizontal area of 302 by 308 meters of the Grasbrook proposal.

For further definition of the Z axis, additional input parameters are important to consider, such as the height of the tallest building to be modelled, which in the case of Grasbrook, a high-rise building of 107 meters is to be considered within the selected area. When high-rise buildings are modelled, an option called telescoping can be used, which helps to run a faster simulation, without affecting the behavior of the first Z grids (*Knowledge Base: Vertical Grid Layout*, n.d.). Ultimately microclimate should be closely assessed in the first meters closer to the ground where pedestrian activity is largely located. So, for a proper calibration of the vertical grids of this model, 40 grid cells of 2 meters are selected for the Z axis and the telescoping factor of 10% is activated after 31 meters. This results overall in a model height of 216 meters, which is more than double the highest building analyzed.

Besides the area defined for the spatial model, another input parameter defined is a surrounding area of additional cells, also known as nesting grids. The amount of nesting grids is proportional to the size of the model. In this case, 12 nesting grids were located around the perimeter of the modelled area, enough to avoid any significant building structures too close to the edges. The nesting grids should only hold surface materials but no built-up structure or vegetation. For the case of Grasbrook, the soil profiles named deep water and loamy soil were selected from the System Database, as it is what mostly surrounds the District, and the software assumes this for the immediate context affecting the physical model. The purpose of the nesting grids is to create a perimeter buffer zone with the characteristics of the lateral boundary conditions appropriate for the simulation, controlling the way the model behaves towards its edges and reducing errors.



RELEVANT OPEN SPACES IN STUDY AREA

- Main street axis (Grasbrook Ring)
- North-South pedestrian axis
- East-West pedestrian axis
- Coastal promenade
- Playgrounds school and daycare
- Sportsfield
- Residential innercourtyards

Figure 32. [Relevant open spaces in study area, based on winning landscape proposal].
Note: Adapted from *1. Rang – Grasbrook Hamburg,* by HafenCity Hamburg GmbH, 2021.
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5.3.2. Digitalization of the Spatial Model.

Once the preliminary conditions are set, the spatial model can be built into the Envi-Met software. It consists basically of soil surfaces, vegetation, building shapes and materials. The modelling process done in Monde is based on geodata imported from Open Street Maps to define the precise geolocation of Grasbrook, this is attainable from within the Envimet program. In addition, shapefiles of the vector model from the Integrative Planning Phase, acquired through the Digital City Science Group at Hafencity University thanks to their research collaboration with HafenCity GmbH, were imported as well into the Monde software of Envimet, to have a more up-to-date version of the proposal. The software transforms the vector information into a grid-based information to be used in Spaces (Figure 33), for the final calibration of the model of Grasbrook. This process reduced significantly the amount of time dedicated to modelling.

Envi-Met Spaces is a pixel-based area, and each cell of the grid must contain information for the model to run the simulation without errors. When using Spaces, materials and profiles can be either selected from the predefined System Database, or custom-made for a more user-specific model. Nevertheless, the predetermined catalog of Envi-Met has a broad selection of materials, so this was chosen for the modelling phase of this study. The materials are defined according to their physical properties.

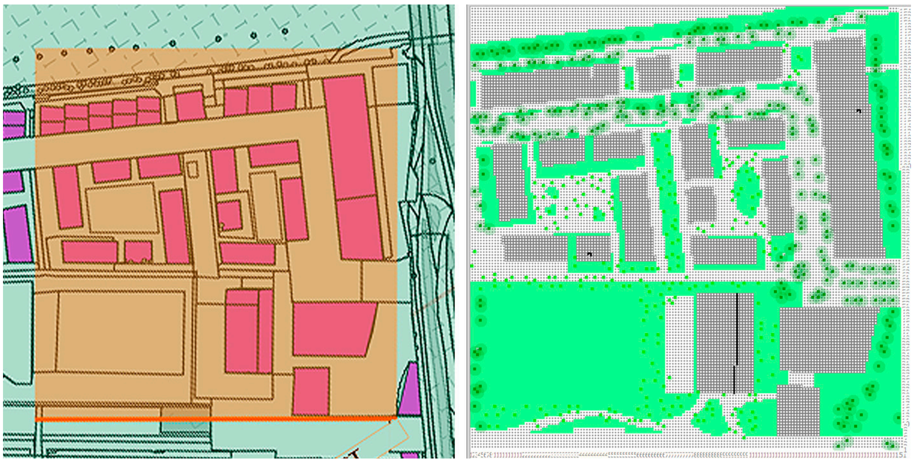

Figure 33. Comparison of the Envi-Met vector-based interface of Monde, left, and the grid-based interface of Spaces, right. *Note:* screenshot taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.

For Buildings Materials: The location of buildings is adapted to the predetermined grid, with their respective heights. In regards to materials, the Grasbrook competition proposal depicts three types of building materials distributed along the selected area of the new District: white-plastered buildings along the northern border towards the coastline, wooden buildings inside the residential blocks and red-brick buildings along the border towards Veddel, to the East side of the new District (see Figure 34). The adaptation to the spatial model resulted in the selection of Default Wall Moderate Insulation as the material from the System Database, for the residential blocks and the higher buildings along the coast and Brick Wall Reinforced for the identified brick buildings. No wood material was selected for the residential blocks because there was no wooded material destined for façades in the catalog of the System Database.

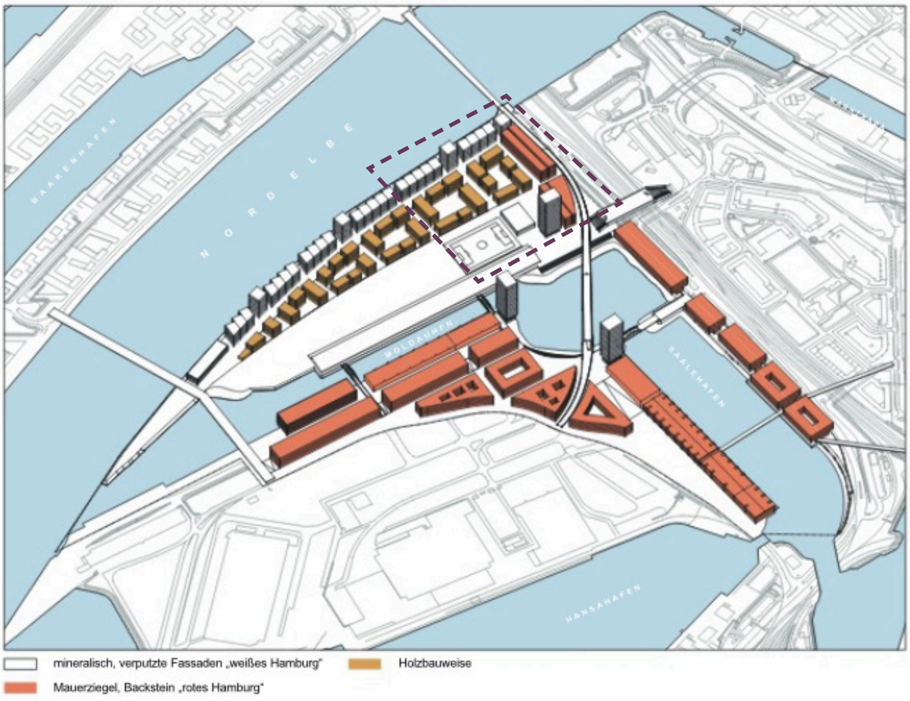

Figure 34. [Facade Materials Concept from the Grasbrook Competition winning urban proposal, with area for simulation highlighted].
Note: Adapted from *1. Rang – Grasbrook Hamburg,* by HafenCity Hamburg GmbH, 2021.
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For Roofs and Façade greening: Once again, the Grasbrook competition proposal shows the location of green roofs on the entire area of study, and green facades in some of the buildings, seen in Figure 35. The adaptation in the model was done, using the catalog from the Envi-Met System Database. For roofs, greening with mixed substrate of 15 cm. without air gaps was selected. For the green facades, greening with mixed substrate of 15 cm. with air gaps was selected.

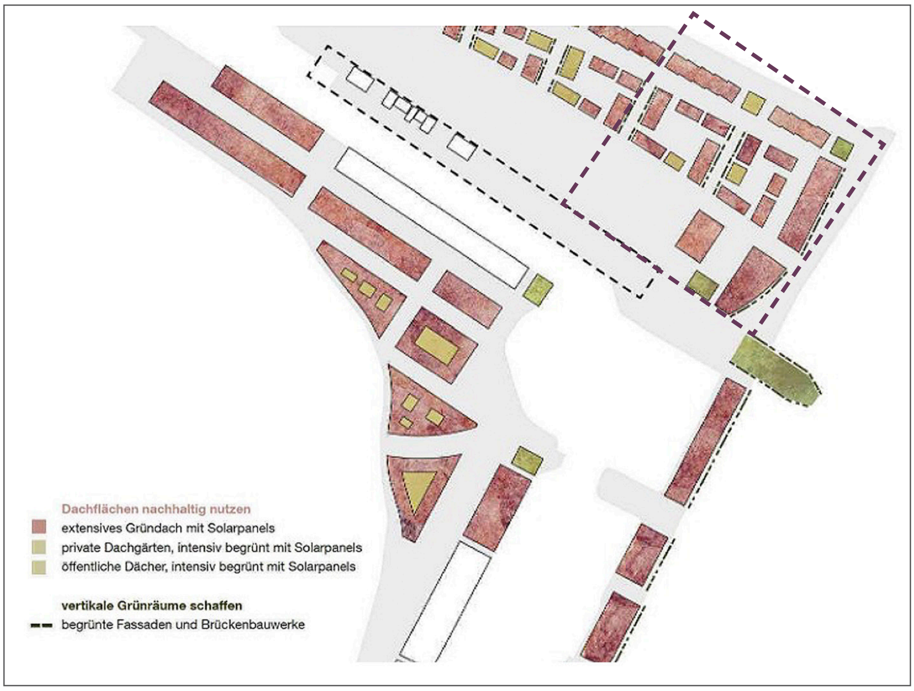

Figure 35. [Green Roofs and Facades Concept from the Grasbrook Competition winning landscape proposal, with area for simulation highlighted].
Note: Adapted from *1. Rang – Grasbrook Hamburg,* by HafenCity Hamburg GmbH, 2021.
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For Vegetation: In the plans from Vogt Landschaftsarchitekten AG, a detailed description of the proposed vegetation over the District was consulted (Figure 36). There is a clear distinction of the types of trees proposed in different areas. Besides the vegetation types, to assess the correct height of the proposed trees, the section drawings were observed and estimations were made. Envi-Met Spaces distinguishes mainly between two types of vegetation selected, Simple Plants refers to surface vegetation like grass or bushes, and 3D Plants refers to trees. Once again, the System Database offers a broad variety of predefined vegetation. For Simple Plants, the type Grass 25 cm. average dense was selected over all areas with grass. For the 3D Plants, all selected tree types are deciduous trees, with distinctions among their shape, height, trunk width and leaf-area density or LAD. In Figure 47 (page 81) the detailed selection and distribution can be observed.

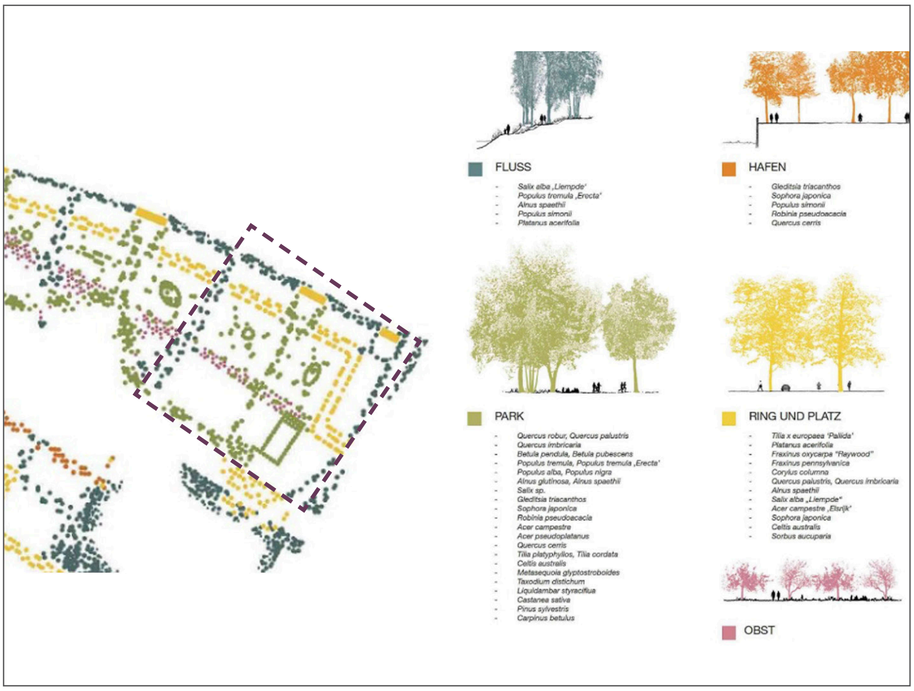


Figure 36. [Tree concept from the Grasbrook Competition winning landscape proposal, with area for simulation highlighted]. *Note:* Adapted from *1. Rang – Grasbrook Hamburg,* by HafenCity Hamburg GmbH, 2021. Copyright 2021 by HafenCity Hamburg GmbH.

For Soils: From the System Database, Asphalt Road was selected for the vehicle paths. Default Unsealed Soil ,Sandy Loam, was selected for the areas along the shore and permeable areas under grass. Deep water was selected for the Elbe River and Canals. Concrete Pavement Light was selected for main sidewalks. Granit Pavement, single stones, was selected for smaller pedestrian pathways and Sandy Soil was assigned to playgrounds areas (Figure 46, p.80).

Once all the described input was assigned to each of the corresponding grids of the District area, the model is reviewed through the Model Inspector, and when no errors are found, it is then ready to run the simulation and assess the urban microclimate of the outdoor space. The overall time for the assembly of the model was approximately 3 days.

5.3.3. Simulation Process.

In order to run the simulation, a following program is used in the Envi-Met headquarters, called Envi-Core. In this section, a simulation file is created in reference to the file from the spatial model. The input parameters for this simulation file include a selected date, time and duration for the simulation, and level of complexity of the climate input parameters, which depending on the level _from beginner to expert_ more parameters are defined by the user and less by the software.

For the simulation date, September 15th, 2020 was selected; the same day as for the field measurements described in chapter 5.2. The data gathered during the field measurements process was considered as input for the simulation, given the advantage of having raised location-specific climatic data, instead of using generic climate datasets. The time period selected is of 24 hours, starting at 6.00 am. The type of simulation is set at Beginner level, but some values can be adjusted to the specific input from the field measurements, such as temperature range, which was by default between 16°C and 28°C and was adjusted to 16°C to 32°C, realistic temperature range measured on this date. Also, the wind speed and direction was calibrated to light speed of average 1 m/s, coming predominantly from the West, according to field measurements.

For the definition of the simulation boundary conditions, simple forcing is selected and applied to the nesting grids, as it is the recommended option to be used from Envi-Met version 4 onwards (*Lateral Boundary Conditions*, 2017). Once the input parameters are defined and the simulation file is checked, with no significant errors, the complete simulation process is calculated. The overall computational time to run a 24-hour simulation lasted 3 days and 16 hours. The output of this process results in a series of folders, containing the individual output files for each of the climate parameters, which will be then analyzed in the following sub-program of the Envi-Met headquarters.

5.3.4. Simulation for Outdoor Thermal Comfort.

Besides the main simulation process, a secondary simulation must run in order to obtain results specifically related to Outdoor Thermal Comfort. This is done through the sub-program called Bio-Met, also in the Envi-Met headquarters. Fewer input parameters are defined, and the simulation time is much shorter. For the case of this study, the entire range of 24 hours is selected, and a vertical range for the Outdoor Thermal Comfort is defined at up to 1.80 meters, because this parameter is only relevant to be measured within the height where pedestrian activity is located.

The type of Thermal Comfort Index must be selected among the default options presented by Envi-Met. Although Envi-Met offers different Indexes for the assessment of Outdoor Thermal Comfort, the Physiological Equivalent Temperature Index, or PET, is the most recommended option (*Biomet_UTCI,* 2020), mainly because it is better related to the type of physical model done by the software. This criteria is also supported by the literature review on the chapter 3. Finally, PET is the Index selected for this simulation, and further analyzed along with the other output files.

5.3.5. Visualization and Analysis of First Results.

The visualization of the output files is done through the Leonardo program. This is produced in the form of maps and the availability to be produced is vast, depending on the output data selected and the targeted parameter that needs to be assessed. Also, the representation of the resulting maps can be calibrated according to how the information is intended to be shown; adjustments in the color palette, scale, legends, type of view, selected timeframe, among other aspects. It can be said from the empirical process of using Leonardo that this phase involves much decision-making and iteration of the produced content in order to focus on specific results.

The objective here is to visually understand the microclimatic conditions in the urban outer spaces of the proposed new Grasbrook District, to identify the appearance of hotspots related to Outdoor Thermal Comfort and to determine whether adaptation measures are necessary through a second simulation to find possible improvements. This was done through an iterative process of producing and analyzing maps, considering the built urban form as well as the meteorological phenomena affecting the pedestrian space. The analysis is then based not purely on microclimate parameters but also on urban notions that can be understood from the structure of the District. After reviewing different results, a final series of maps were selected, given their relevance to the proposed objective. The selected parameters to look at and the corresponding maps are:

Regarding Building Heights: *Sky View Factor Map.*
Regarding Street Canyons: *Direct SWR Maps.*
Regarding Soil Surfaces: *T Surface Maps.*
Regarding Vegetation: *LAD 3D Views.*
Regarding Facades and Greening: *Facades Surface Temperature 3D Views*
Regarding Wind affectation: *Air Temp with Wind Maps / Tubular Bells 3D Flow.*
Regarding Outdoor Thermal Comfort: *PET Maps.*

Regarding Building Heights: The Sky View Factor Map (Figure 37) allows to have a general overview of the relationship between the built area and the open space in between, understood from the perception of how much sky view an individual has from a specific standing point. As explained by Hussein et al. (2017), the usefulness of the Sky View Factor (SVF) relates to a better understanding of the built urban form and the microclimatic factors affecting it, contributing to the design of urban spaces with sustainable considerations like climate, comfort and energy. As it can be understood from the legend, the range going from 0, in blue, defines the highest obstruction of sky views, up to a level of 1, in pink, defining the areas where the sky visibility is absolute. In the case of Grasbrook there is a progressive increase of the sky view factor which correlates to the degree of privacy or public of the open urban spaces. Areas like the sport field or the northern coastal promenade shows a higher level of sky visibility, while the residential inner courtyards and smaller pedestrian streets have a lower range of view. It is important to mention that this Index considers the presence of high vegetation as an obstacle for the sky views, as it can be seen along the Grasbrook Ring, or main vehicle street, although this also denotes an urban space with good shading.

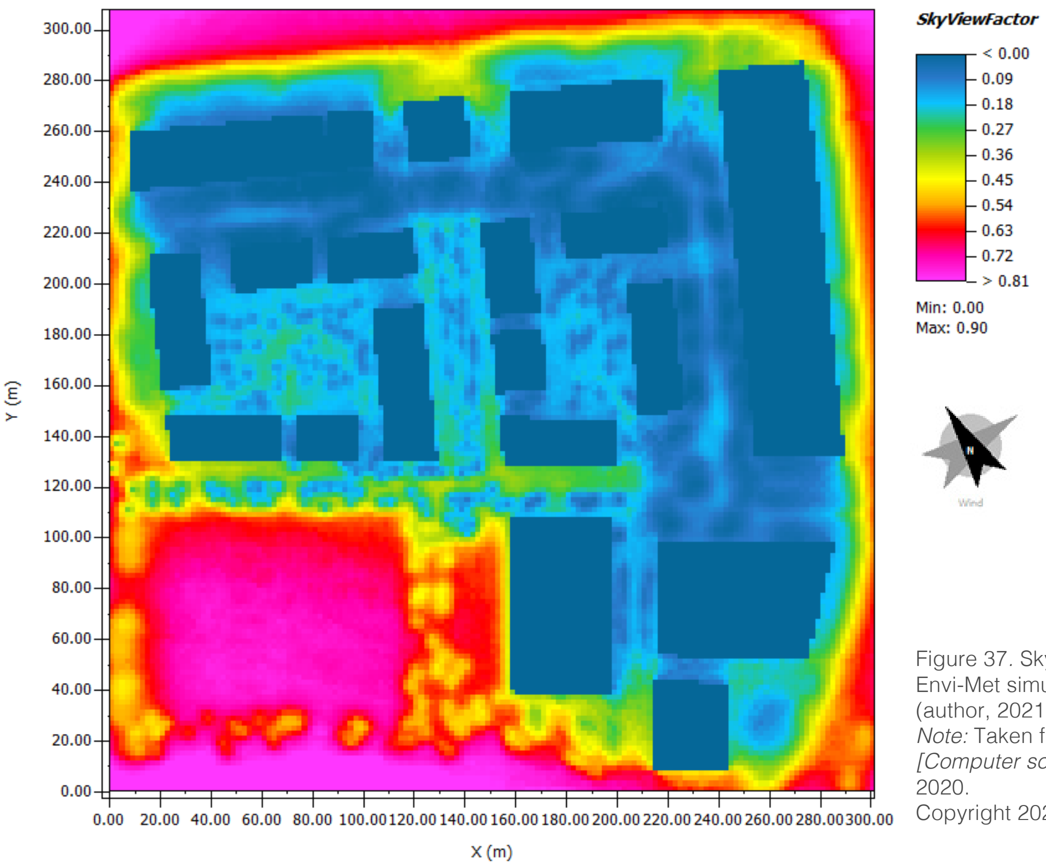


Figure 37. Sky View Factor 2D Map, Envi-Met simulation from 15.09.2020 (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.

Regarding Street Canyons: In order to understand the daylight incidence over the street canyons according to their orientation and width, a series of direct shortwave radiation (SWR) maps are produced, seen in Figure 38. The idea behind the use of a sequence of maps, comes from the necessity to understand the changes in the radiation and shading along the different hours of the simulated day, as one single instant does not give a broad enough overview of the entire situation. Generally, the East-West oriented street canyons have a greater tendency towards shading along the day; more than the North-South oriented streets which show a better balance between sun and shading hours along the day, with a specific time at 14.00 hours of absolute SWR over the pedestrian street between both residential blocks. With the gathered observation of the SVF and SWR maps, it can be assessed that the location of buildings and street canyons orientation do not show serious conflicts in this segment of the district, and also that the presence of vegetation plays an important role in the radiation levels over the open space.

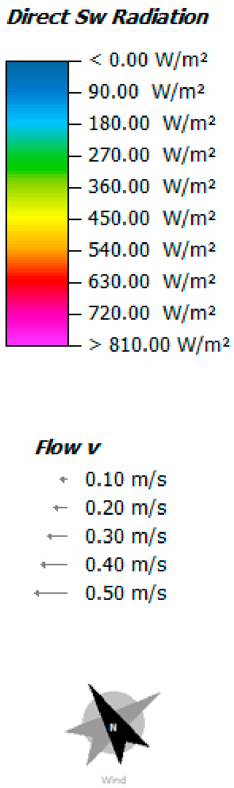
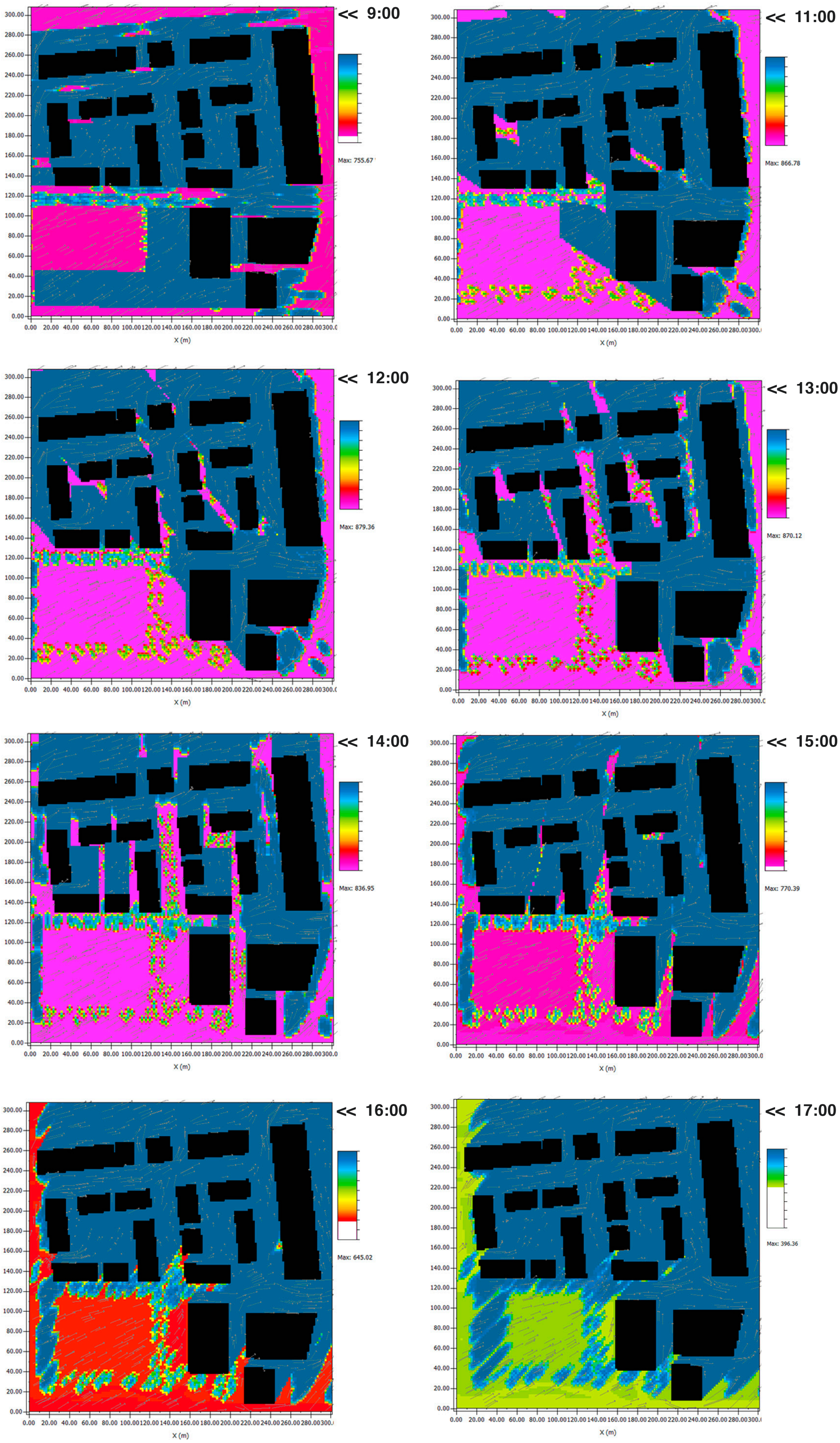


Figure 38. Sequence of 2D maps depicting direct SWR with wind flow, ranging from 09.00 to 17.00 hours (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.



<< 9:00
Max: 755.67
<< 11:00
Max: 866.78
<< 12:00
Max: 879.36
<< 13:00
Max: 870.12
<< 14:00
Max: 836.95
<< 15:00
Max: 770.39
<< 16:00
Max: 645.02
<< 17:00
Max: 396.36
X (m)

Regarding Soil Surfaces: The T Surface Maps (Figure 39) show the temperature at level zero of the area studied, or ground surface temperature. It has a strong relation between radiation received and the albedo of the materials selected for the ground surfaces. In the case of this study, once again a series of maps were produced hourly, here showing a period from 10.00 to 19.00 hours. The hotspots identified register a ground surface temperature reaching over 37°C between the period of 13.00 and 15.00 hours, affecting the open spaces of one of the two daycare facilities and the elementary school.

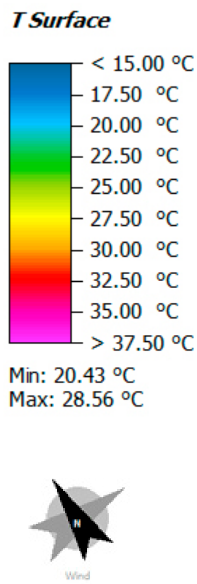
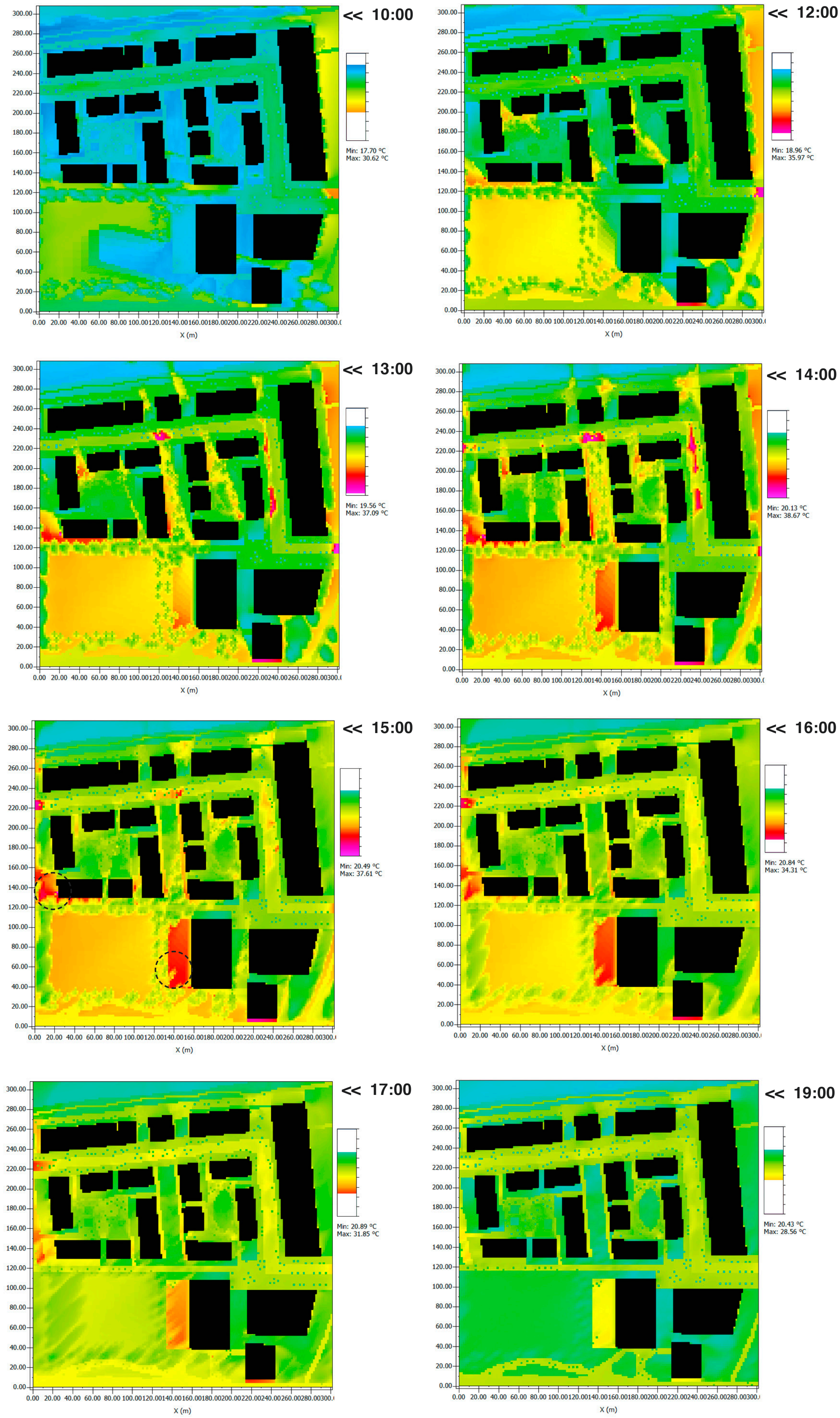


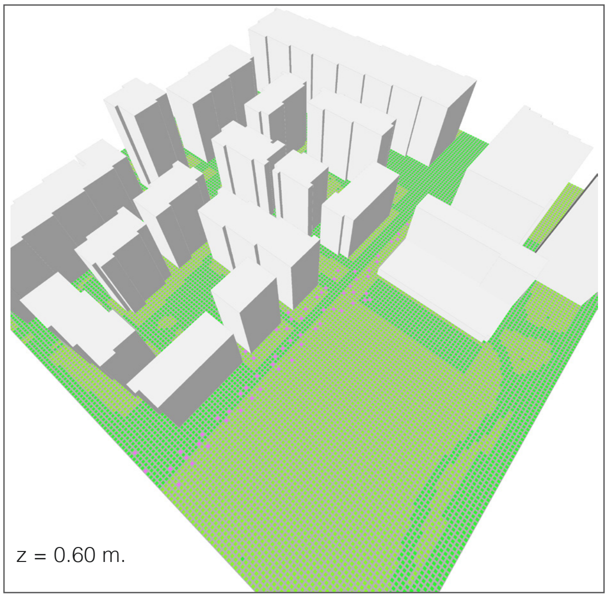
Figure 39. Sequence of 2D maps depicting temperature on ground surface, ranging from 10.00 to 19.00 hours (author, 2021). *Note:* Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.

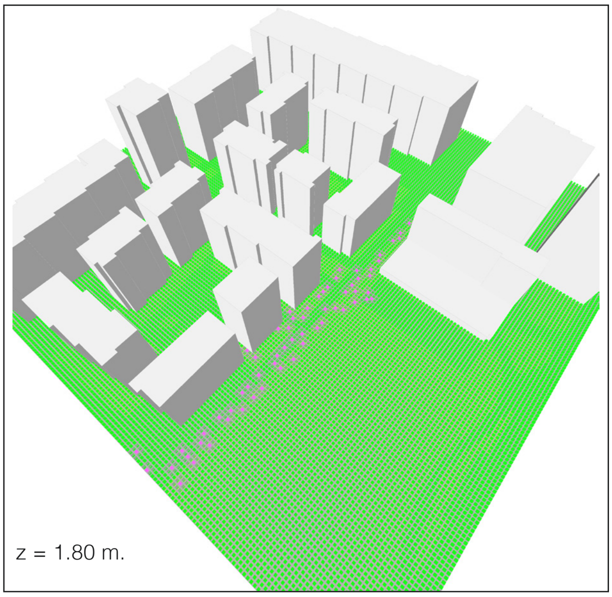


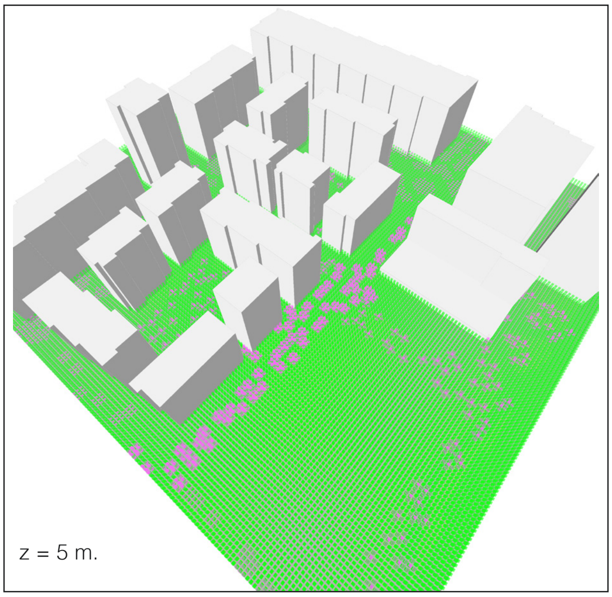
<< 10:00
Min: 17.70 °C
Max: 30.62 °C
<< 12:00
Min: 18.96 °C
Max: 35.97 °C
<< 13:00
Min: 19.56 °C
Max: 37.09 °C
<< 14:00
Min: 20.13 °C
Max: 38.67 °C
<< 15:00
Min: 20.49 °C
Max: 37.61 °C
<< 16:00
Min: 20.84 °C
Max: 34.31 °C
<< 17:00
Min: 20.89 °C
Max: 31.85 °C
<< 19:00
Min: 20.43 °C
Max: 28.56 °C
X (m)

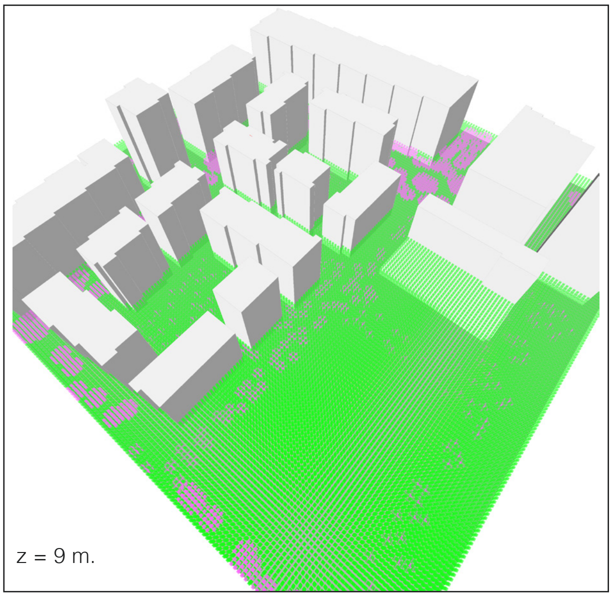
Regarding Vegetation: As it was understood previously by the SVF and direct SWR maps, the role of vegetation has clear influence on the microclimate of the open spaces. Furthermore, Zölch et al. (2019) argument the importance of considering Urban Green Infrastructure (UGI) to diminish heat stress and improve the overall microclimate condition of an open space through the physics of increased shading, evapotranspiration and wind circulation. In order to visualize this more clearly, a series of 3D visualizations of the model are produced, where the Leaf Area Density (LAD) of trees can be assessed. LAD is measured in m2/m3 and it represents the distribution of leaf surface in a specific cubic area of space, seen in pink (*Obtaining Leaf Area Density Data*, 2017). The 3D views in Figure 40 detail horizontal cross sections done at different heights, in order to better understand the incidence of shading on different street axes of the proposal. It is observed how the highest LAD value found on the East-West pedestrian street north of the sports field appears to be at 5 meters height, which could contribute partly to the higher temperature on this area at ground surface, as discussed previously with the T Surface maps. This situation is also visible towards the East side of the sports field, bordering with the elementary school playground. On the other hand, a higher LAD level is registered at the 13-meters horizontal section, along the Grasbrook Ring, which correlates also to the reduced temperature shown in the T Surface maps along this area. It can therefore be concluded that the adequate height for tree canopies should be above 10 meters in order to provide better shading and reduced temperatures caused by direct SWR.

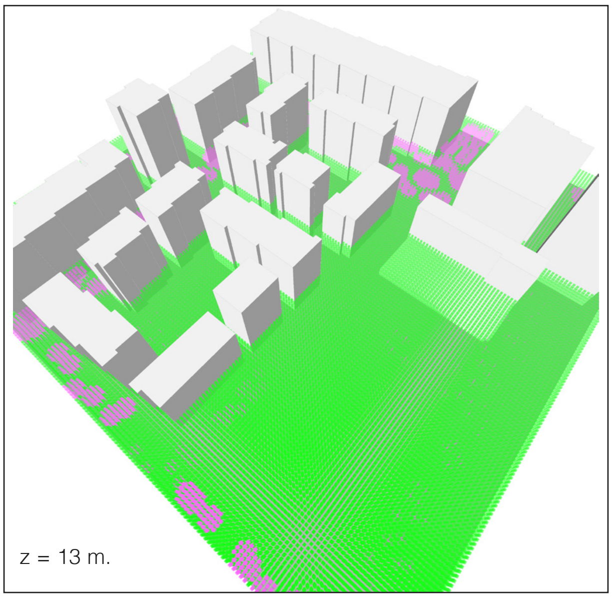
Figure 40. 3D views of LAD on vegetation at different heights, seen in horizontal sections (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

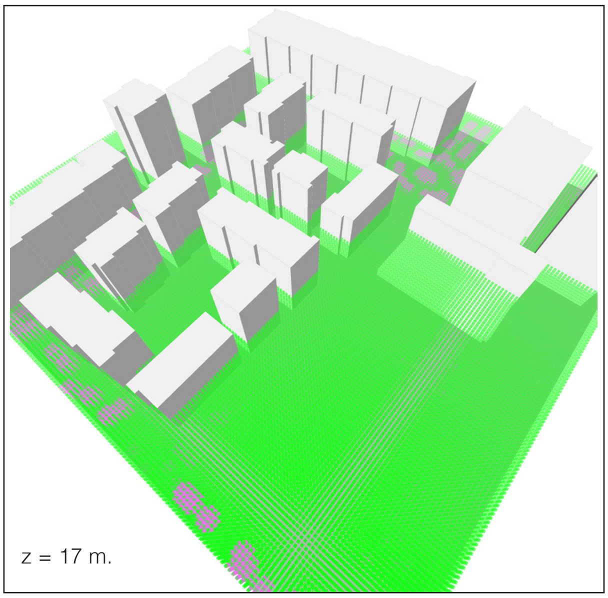

z = 0.60 m.


z = 1.80 m.


z = 5 m.


z = 9 m.


z = 13 m.


z = 17 m.

Regarding Facades and Greening: As explained previously when referring to UGI, in addition to street vegetation, it is useful to assess the effect of greening on the facades of the proposal. 3D views representing the temperature on the facades surfaces were produced hourly in a range, here showing from 09.00 to 16.00 hours (Figure 41), to compare the difference in temperature registered along the day, over facades with and without greening. What can be observed from this timeline is both, the changing incidence of daylight over the building surfaces, and the resulting temperature over the buildings, which of course also depends on the albedo of the materials selected for each vertical surface. From this observation, a distinct differentiation can be made between the buildings highlighted at 11:00, where a façade with greening and one without greening, despite having the same orientation, show a difference of over 20°C. In addition, most of the facades facing south towards the sports field can be highlighted as a hotspot for heat stress from 14.00 hours to 17 hours, which contributes to the previous assessment of the low trees along this area. In general, it can be seen from these 3D views, that the buildings modelled with the Brick Wall Reinforced material have a better resistance to heat than those with the Default Wall, Moderate Insulation material.

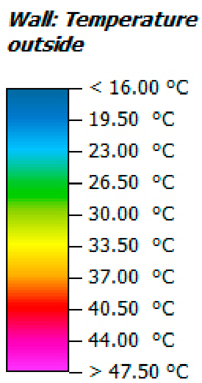
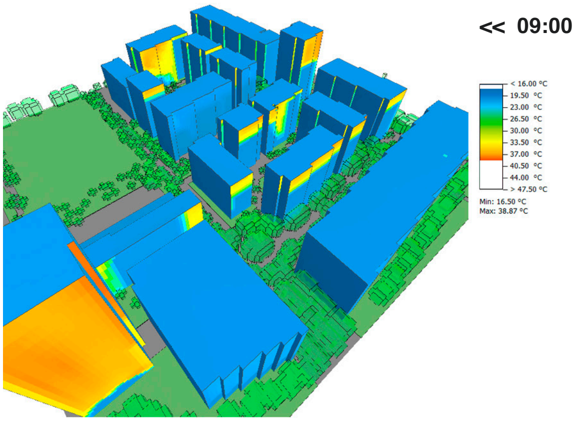
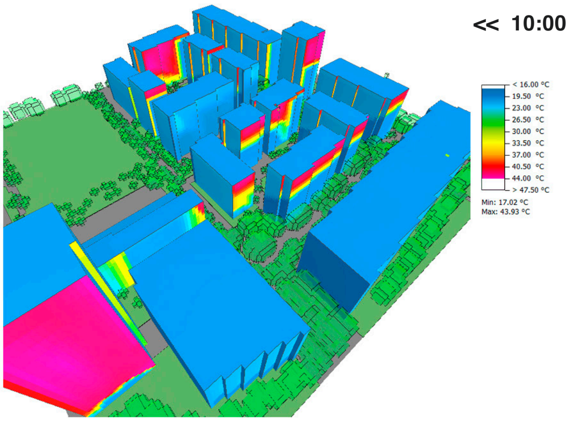
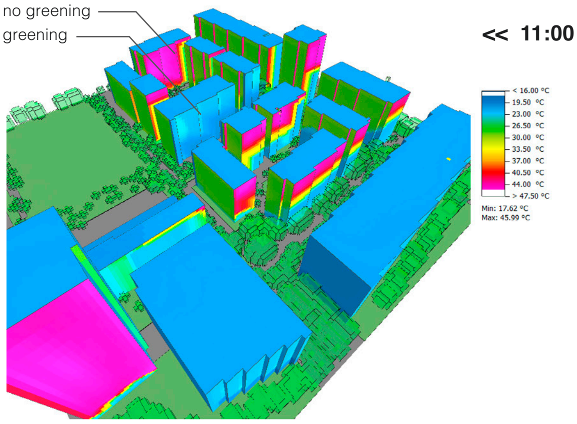
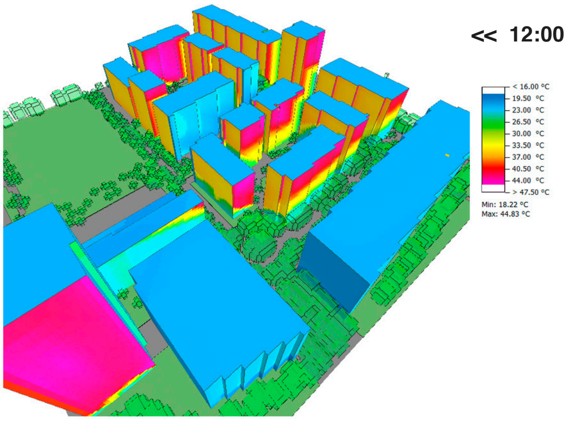


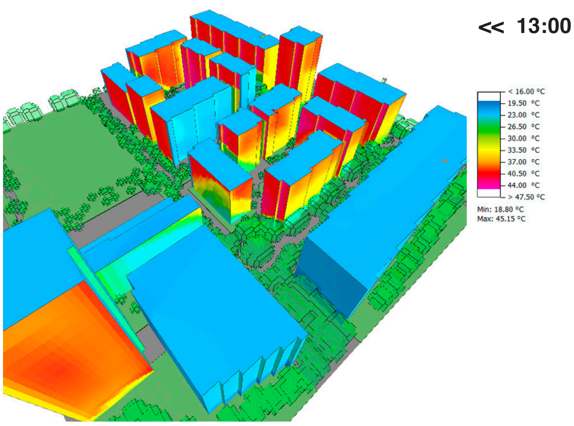
Figure 41. Sequence of 3D views depicting surface temperature on facades, ranging from 09.00 to 16.00 hours (author, 2021). *Note:* Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.

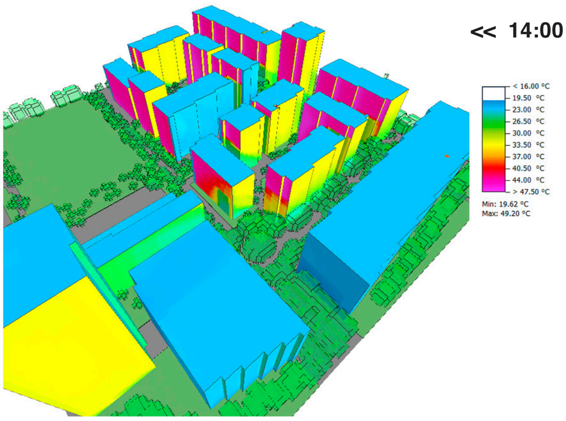

<< 09:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 16.50 °C
Max: 38.87 °C

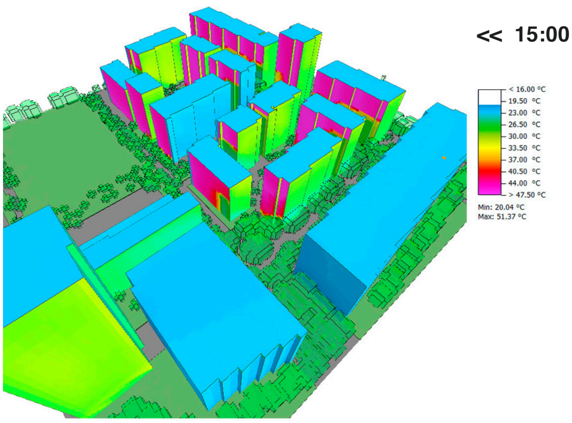

<< 10:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 17.02 °C
Max: 43.93 °C

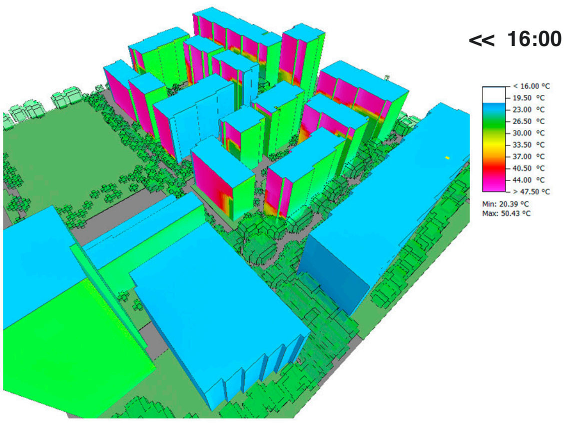

no greening
greening
<< 11:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 17.62 °C
Max: 45.99 °C


<< 12:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 18.22 °C
Max: 44.83 °C


<< 13:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 18.80 °C
Max: 45.15 °C


<< 14:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 19.62 °C
Max: 49.20 °C


<< 15:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 20.04 °C
Max: 51.37 °C


<< 16:00
< 16.00 °C
19.50 °C
23.00 °C
26.50 °C
30.00 °C
33.50 °C
37.00 °C
40.50 °C
44.00 °C
> 47.50 °C
Min: 20.39 °C
Max: 50.43 °C

Regarding Wind affectation: The behavior of the wind flow over the District was assessed with two different types of maps produced in the Leonardo program of Envimet. First, a series of hourly 2D maps show the wind speed between the built area along with vector flows which also denote the wind movement (Figure 43). From these maps, there isn't a significant variation along the day, but areas of attention can be identified, where the narrow disposition between the buildings along with the incoming direction of the wind flow show a funnel effect, increasing lightly the wind speed. Nevertheless, it is understood that the maximum speed registered on this simulated day is under 2 m/s and does not pose any stress situation for pedestrians. Special attention can be paid to the situation inside the residential courtyards, where the 2D maps show very low wind movement (Figure 42).

For a more complete overview of the wind flow behaviour in this area of the District, a 3D view of the simulated model is produced, where the wind flow can be observed in its three dimensions, through the representation of wind with tubular bells (Figure 43). The color of the tubular bells and the 3D grid among the building structure is determined by the same color palette of the wind speed legend in the 2D maps, ranging from dark blue as stagnant wind up to dark pink as maximum registered wind speed. Here it can be better understood how the wind flow maintains a variable speed along the East-West axis, North of the sports field, while within the residential courtyards and North-South pedestrian streets, the wind does not seem to enter with strength, but instead hovers over the built area. As the wind vectors move upwards towards the roof area of the buildings, an increase in speed can be seen, in red-colored vectors, over two of the rooftop areas where habitable rooftops area proposed. Special considerations can be given to these rooftops for wind protection, although it is important to remember that what is being assessed here is a single-day scenario of wind affectation.

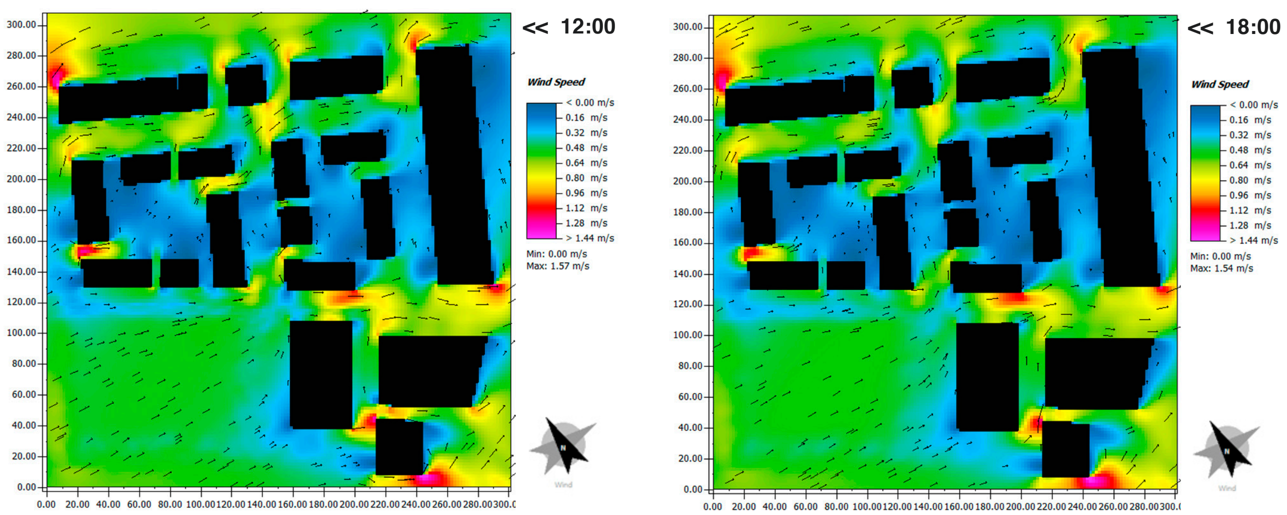


Figure 42. 2D maps depicting wind direction and speed at 12:00 and 18:00 hours (author, 2021). *Note:* Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.

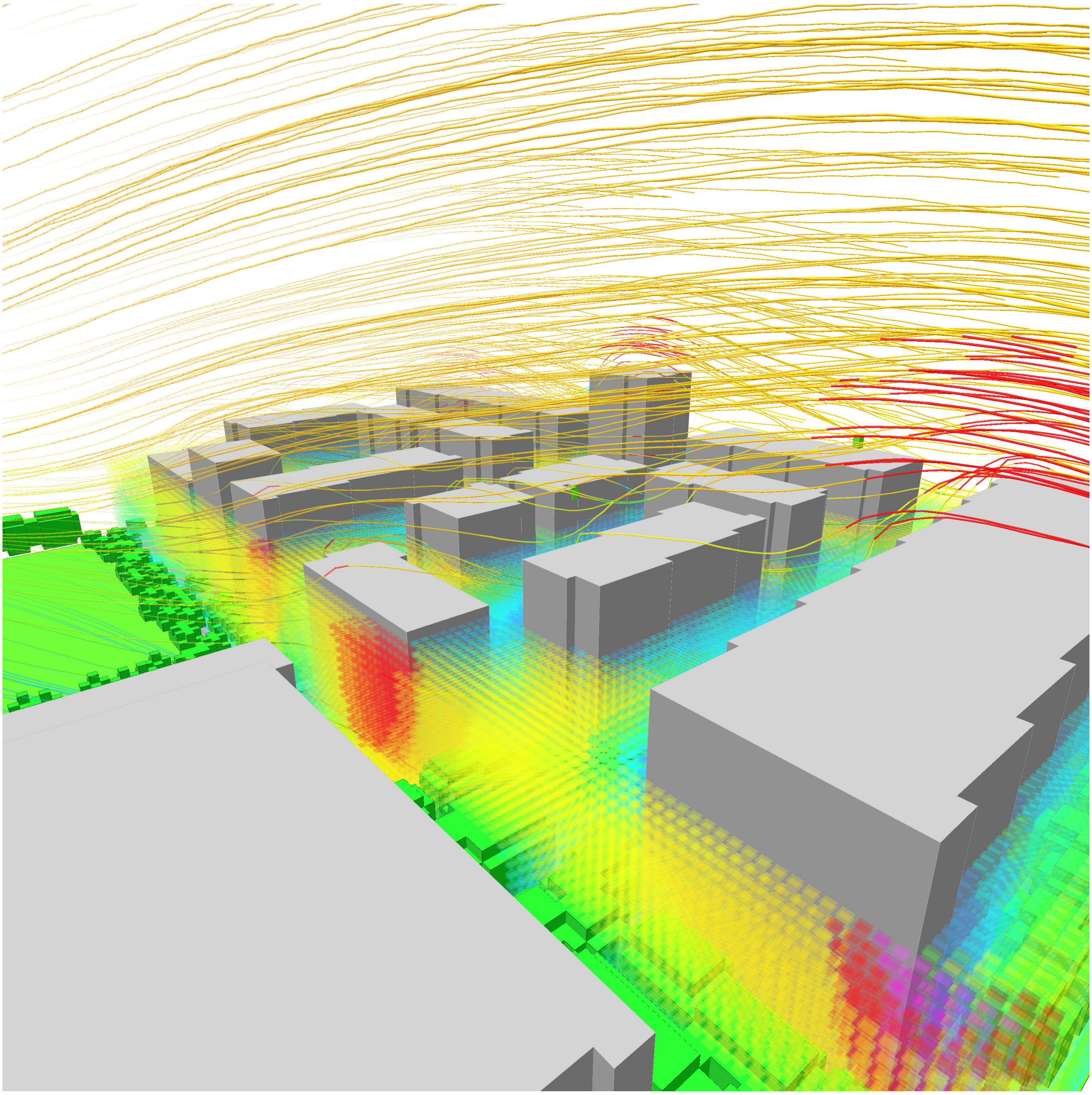
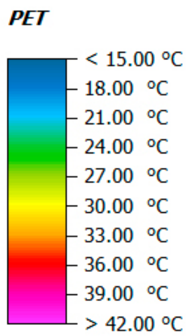


Figure 43. 3D view depicting wind speed in colored spatial grid and wind flow in tubular bells (author, 2021). *Note:* Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

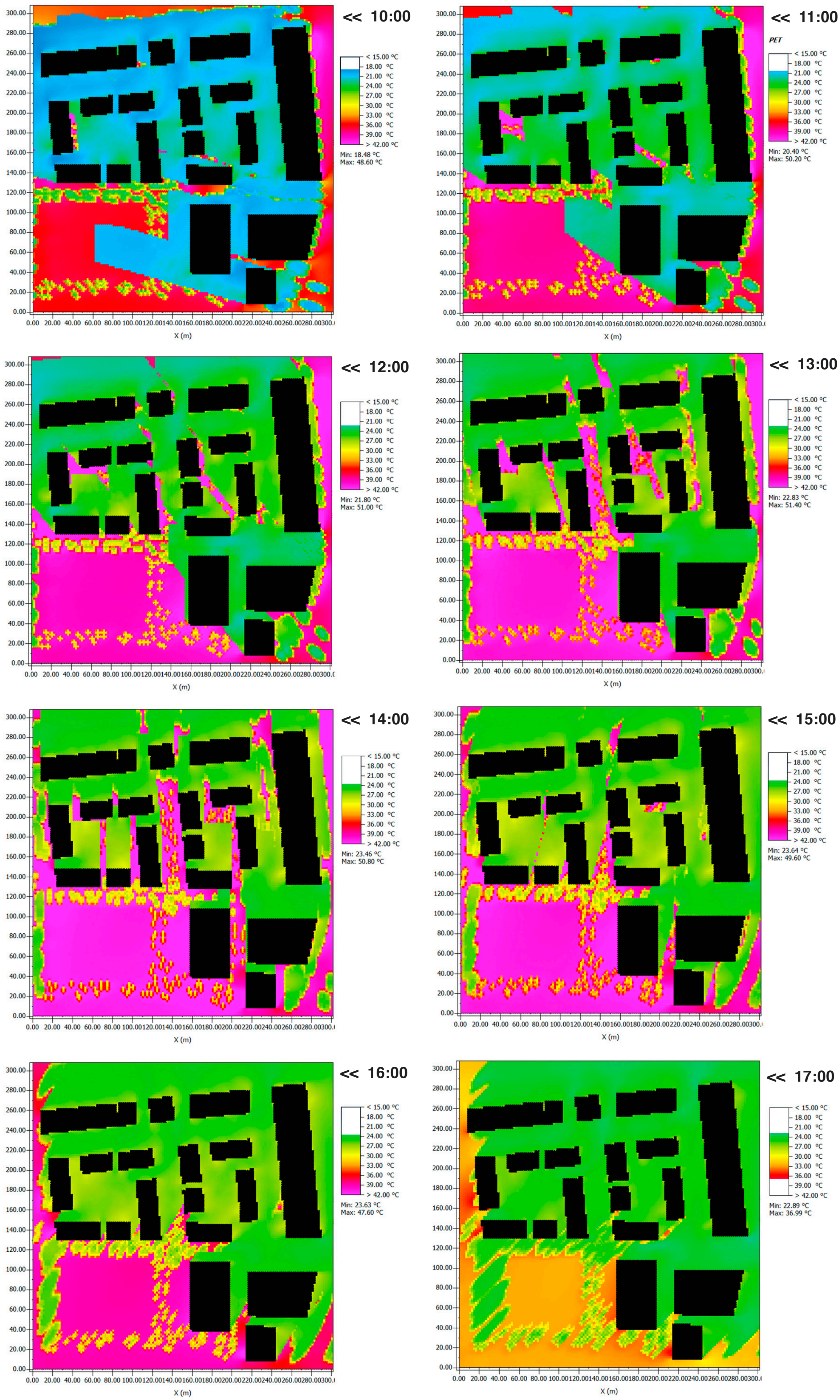
Regarding Outdoor Thermal Comfort: As explained in the sub-chapter regarding the simulation process, the PET Index is selected for the assessment of Outdoor Thermal Comfort. Since the PET values are affected by dynamic physical parameters of the microclimate, such as air temperature, radiant temperature, wind and humidity, it was relevant to produce once again hourly 2D maps, here showing from 10:00 to 17:00 hours of the simulated date, in order to understand the variations and peak situations during one day. As the PET maps produced by the Leonardo program from the Envi-Met headquarters do not provide a reference to the PET scale for Outdoor Thermal Comfort, but only a legend in degrees; it is necessary to compare the results to the PET scale as an additional process in order to identify possible areas suffering physiological heat stress. From the PET scale it is observed that any outdoor space with a PET level above 35°C can be categorized as an area with strong physiological heat stress. In the images shown in Figure 44, it can be seen how the hotspots differ along the different times of the day, but special attention can be given to the overall area of the sports field between 10.00 and 16.00 hours; the playground area in the Elementary School from 12.00 to 16.00 hours; and the North-South pedestrian walkways between the residential blocks and East of the Elementary School from 13.00 to 14.00 hours. It is important to mention that the maximum heat stress level registered surpasses 51°C at 13.00 hours, which is much higher than the existing limit of the PET scale, and supports the studies by Nouri et al. (2018) which confirm that new levels are required for the PET scale (Table 07), in regards to the consequences of Climate Change. Overall, the identified hotspots for Outdoor Thermal Discomfort coincide relatively well with the previously identified areas from the other maps presented. Thanks to the gathered assessments from all other microclimate parameters reviewed in this chapter, a series of recommendations for possible measures to improve the PET values can be made for the Grasbrook proposal.

Figure 44 (opposite page). Sequence of 2D maps depicting PET values, ranging from 10:00 to 17:00 hours (author, 2021). *Note:* Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.



PET	Physiological Stress Grade	
18°C	Slight Cold Stress	Existing Grades
	No Thermal Stress	
23°C	Slight Heat Stress	
29°C	Moderate Heat Stress	
35°C	Strong Heat Stress	
41°C	Extreme Heat Stress (LV1)	
46°C	Extreme Heat Stress (LV2)	New Required Grades
51°C	Extreme Heat Stress (LV3)	
>56°C	Extreme Heat Stress (LV4)	

Table 07. [PET Scale, indicating new required grades of heat stress]. *Note*: From *Confronting potential future augmentations of the physiologically equivalent temperature through public space design: The case of Rossio, Lisbon,* by S.Nouri et al., 2018.



<< 10:00
Min: 18.48 °C
Max: 48.60 °C
<< 11:00
PET
Min: 20.40 °C
Max: 50.20 °C
<< 12:00
Min: 21.80 °C
Max: 51.00 °C
<< 13:00
Min: 22.83 °C
Max: 51.40 °C
<< 14:00
Min: 23.46 °C
Max: 50.80 °C
<< 15:00
Min: 23.64 °C
Max: 49.60 °C
<< 16:00
Min: 23.63 °C
Max: 47.60 °C
<< 17:00
Min: 22.89 °C
Max: 36.99 °C
X (m)

5.3.6. Proposed Measures, Iteration and Final Results.

Based on the analysis previously described and the observations done through the field measurements activity, the following adaptive measures can be proposed for the Grasbrook spatial model, and will be tested through an iterative process of a second simulation (see Figure 45).

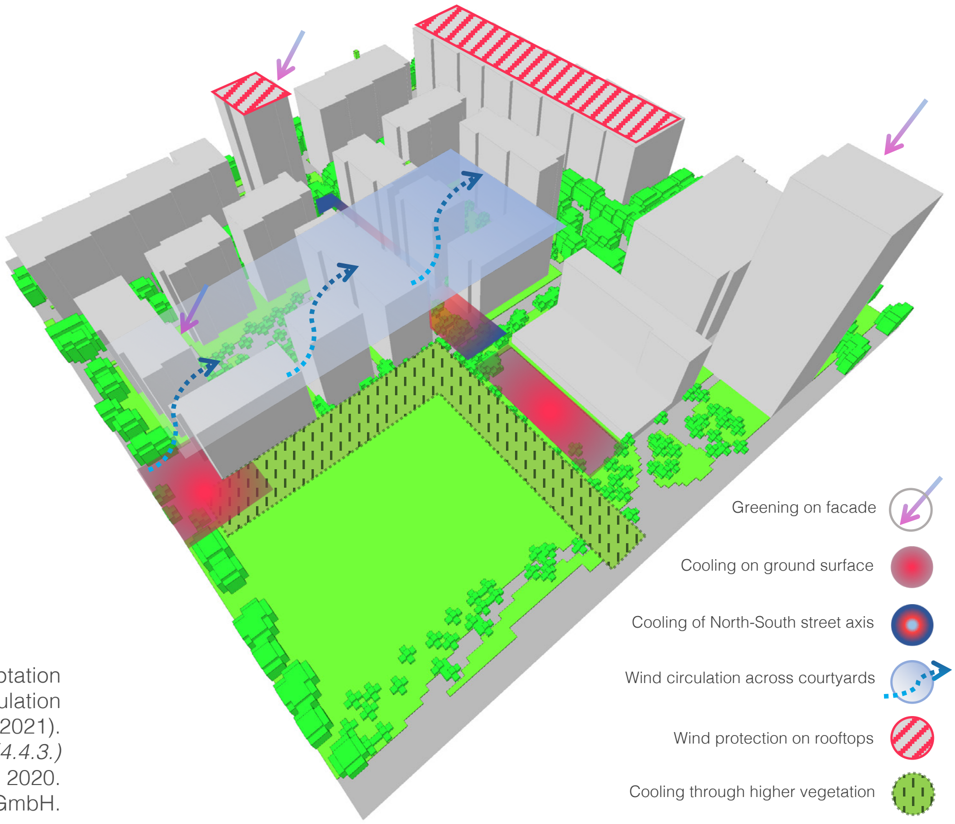


Figure 45. Proposed adaptation measures, based on first simulation results (author, 2021).
Note: Adapted from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.

Proposed Measures for Building Heights: no significant changes seem necessary.

Proposed Measures for Street Canyons: no significant changes seem necessary.

Proposed Measures for Soil Surfaces: The selected ground surface materials in the areas identified as hotspots should be modified for a material with a higher albedo value, especially around the daycare and the elementary school playground which registered high surface temperature. Although the Grasbrook Ring did not reveal high values, this can be attributed to the shading of the trees proposed in the model. It is therefore recommended anyways that also a different material is chosen for the asphalt surfaces as well. The new proposed ground surface materials can be seen in Figure 46.

Proposed Measures for Vegetation: Substitute all 5-meter high trees in the model by 15-meter high trees, according to the analysis made regarding the importance of the shading provided by tree canopies. This contributes to better shading and wind circulation in areas such as those around the sports field, the inner courtyards of the residential blocks and the North-South pedestrian pathways. Figure 47 provides more detail on the modifications implemented in the model.

Proposed Measures for Facades and Greening: Green facades with the same characteristics as the first ones inserted into the model are proposed for the three additional buildings identified in the previous analysis as those with high surface temperatures (Figure 48). In addition, the selection of building materials is reviewed and in the case of the residential blocks, the previously selected material is substituted, for one closer to the albedo of wood facades, as in the Grasbrook proposal. Since the System Database catalog from this Envi-Met version does not offer a wood material for facades, this had to be created as part of a User Profile Database linked to the model. The criteria to establish the appropriate physical properties of the created material can be seen in further detail in Annex C.

Proposed Measures for Wind affectation: For wind affectation no significant changes are done in the model. Nevertheless, more permeability in the ground-floor of the residential blocks is recommended to be considered for more intensive wind circulation. This is not adjusted in the spatial model of Envi-Met because it would require a level of design detail which is out of the scope of this study.

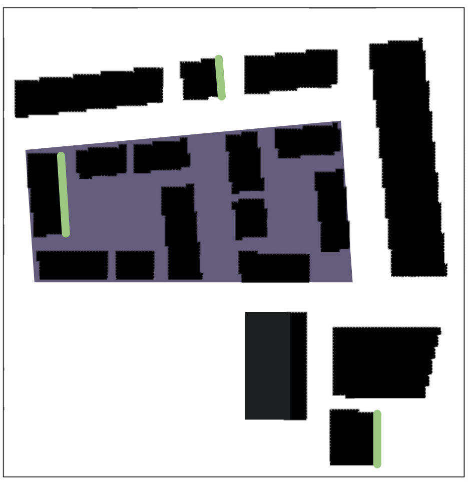
Proposed Measures for Outdoor Thermal Comfort: No specific adjustments for PET are performed in the spatial model. Instead, the adaptive measures described for the other parameters assessed, should reflect a change in the PET values, after the Envi-Met model is adjusted to the described modifications and the new simulation is finished.

Outcome after Second Simulation.

In order to verify if the proposed measures have a positive effect on the microclimate conditions of the Grasbrook proposal, especially regarding the PET values, a second simulation based on the modified spatial model is needed. This second simulation must maintain the same characteristics as the first simulation described in chapter 5.3, so the results of both scenarios can be comparable. The total time needed for the second 24-hour simulation was 3 days, 10 hours and 42 minutes, a few hours shorter than the first simulation attempt. A comparative view of the results from the first scenario and second scenario with the proposed measures are shown in Figures 49 - 52.

Settings in First Simulation		Adjustments for Second Simulation
Granite Pavement, single stone	> >	Basalt Brick Road
Granite Pav., single stone (school)	> >	Grass 25cm, average dense.
Sandy Soil	> >	Grass 25 cm, average dense.
Asphalt Road	> >	Asphalt Road with Red Coating
Concrete Pavement Light	> >	no changes

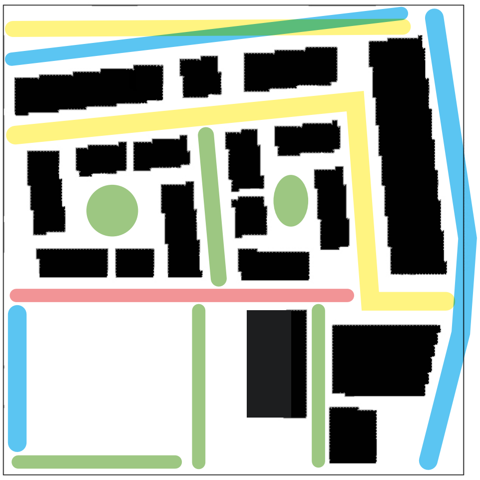
Figure 46. Modifications on Soil settings for second simulation (author, 2021).
Note: screenshots taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.



Adjustments for Second Simulation

- Additional Green Facades
- Wooded Facades

Figure 48. Modifications on Facade materials for second simulation (author, 2021).
Note: Adapted from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020. Copyright 2021 by Envi-Met GmbH.



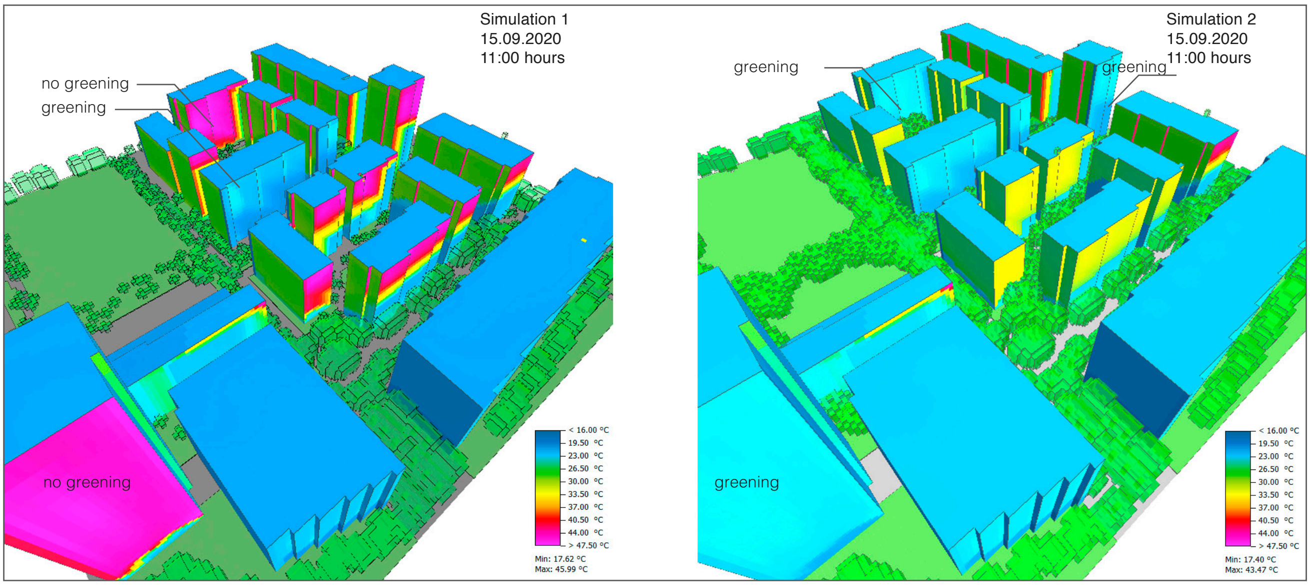
Settings in First Simulation		Settings for Second Simulation
TYPE: Decidous **SHAPE:** Cylindric **TRUNK:** Medium **HEIGHT:** 15 m. **LAD:** High	> >	**(no changes)**
TYPE: Decidous **SHAPE:** Heart-shaped **TRUNK:** Small **HEIGHT:** 5 m. **LAD:** Small	> >	**TYPE:** Deciduous **SHAPE:** Heart-shaped **TRUNK:** Medium **HEIGHT:** 15 m. **LAD:** High
TYPE: Decidous **SHAPE:** Spherical **TRUNK:** Medium **HEIGHT:** 5 m. **LAD:** Small	> >	**TYPE:** Deciduous **SHAPE:** Spherical **TRUNK:** Medium **HEIGHT:** 12 m. **LAD:** High
TYPE: Deciduous **SHAPE:** Cylindric **TRUNK:** Large **HEIGHT:** 15 m. **LAD:** High	> >	**(no changes)**

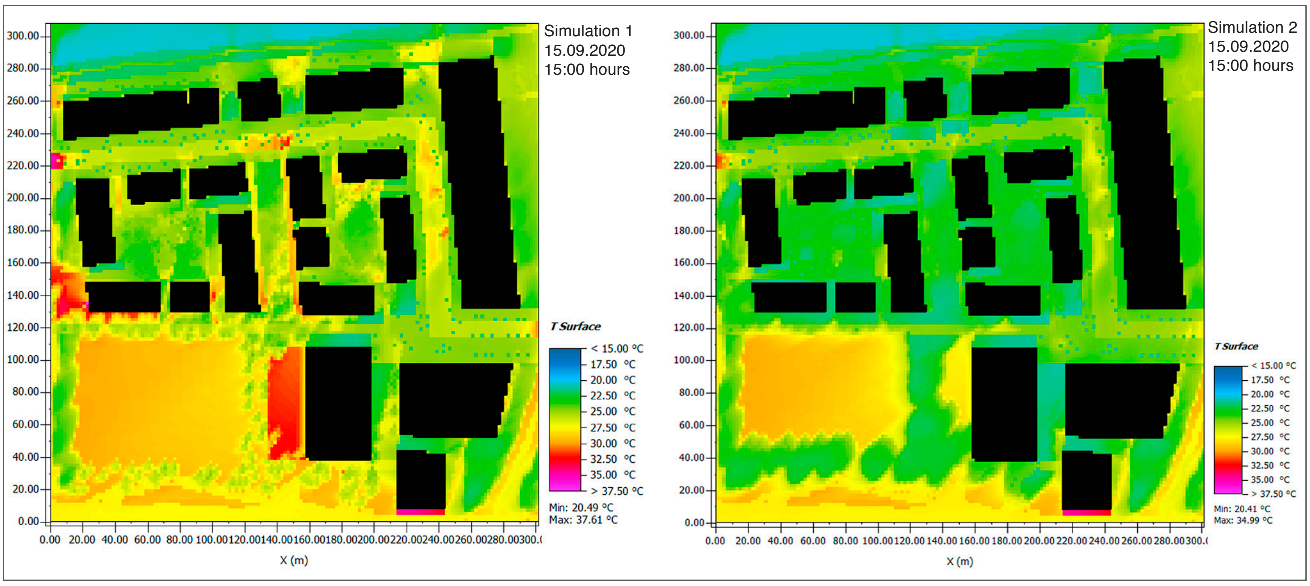
Figure 47. Modifications on Vegetation settings for second simulation
(author, 2021).
Note: Adapted from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

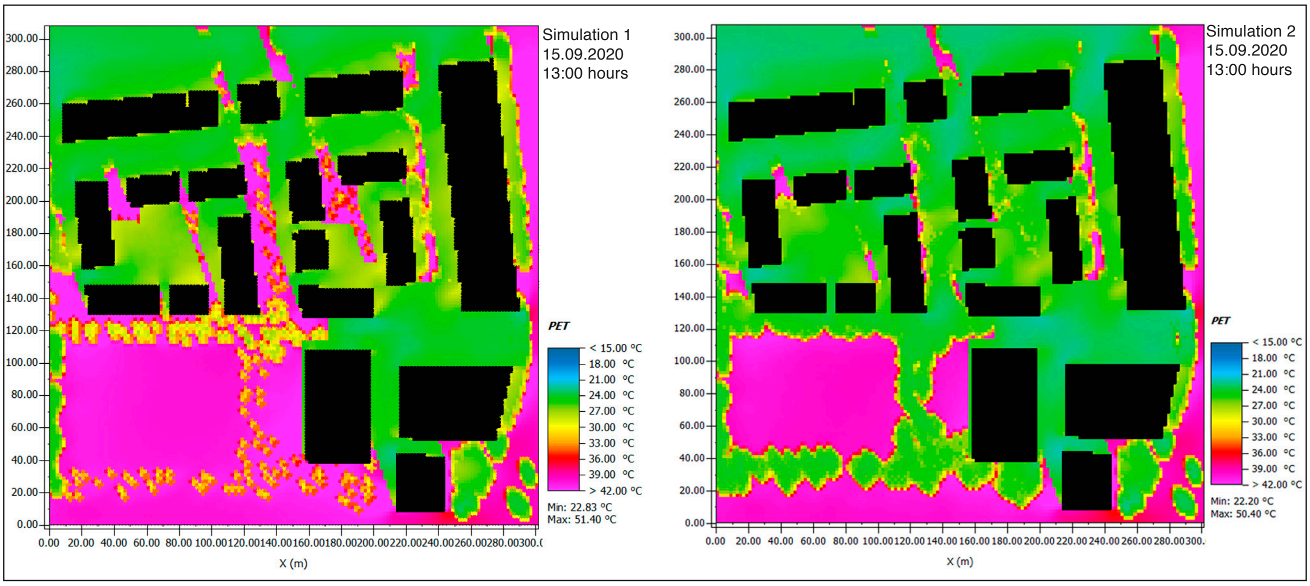
Figure 49 illustrates the improvement seen in the temperature of the facade surfaces, when comparing a 3D view from the two scenarios at the same hours, 11:00 am. The facades now composed of wooded materials present reduced temperatures, and those with greenery even a greater reduction.

In Figure 50, the ground surface temperature presents also improvements, especially in the critical areas identified on the first scenario simulated. The comparative images, both at 15:00 hours, depict the achieved reduced temperatures around the school and day care playground.

In the case of Figure 51, a clear comparison of the PET values from both scenarios is observed. This comparison evidences how a significant improvement in the PET values of the proposal can be achieved when addressing design elements related to urban greenery such as trees and green facades, as well as ground surface and façade materials. Finally, Figure 52 summarizes the absolute temperature difference achieved for Outdoor Thermal Comfort levels in the entire studied area, with a maximum reduction of over 23 K.


Simulation 1
15.09.2020
11:00 hours
no greening
greening
no greening
Min: 17.62 °C
Max: 45.99 °C
Simulation 2
15.09.2020
11:00 hours
greening
greening
greening
Min: 17.40 °C
Max: 43.47 °C


Simulation 1
15.09.2020
15:00 hours
T Surface
Min: 20.49 °C
Max: 37.61 °C
X (m)
Simulation 2
15.09.2020
15:00 hours
T Surface
Min: 20.41 °C
Max: 34.99 °C
X (m)


Simulation 1
15.09.2020
13:00 hours
PET
Min: 22.83 °C
Max: 51.40 °C
X (m)
Simulation 2
15.09.2020
13:00 hours
PET
Min: 22.20 °C
Max: 50.40 °C
X (m)

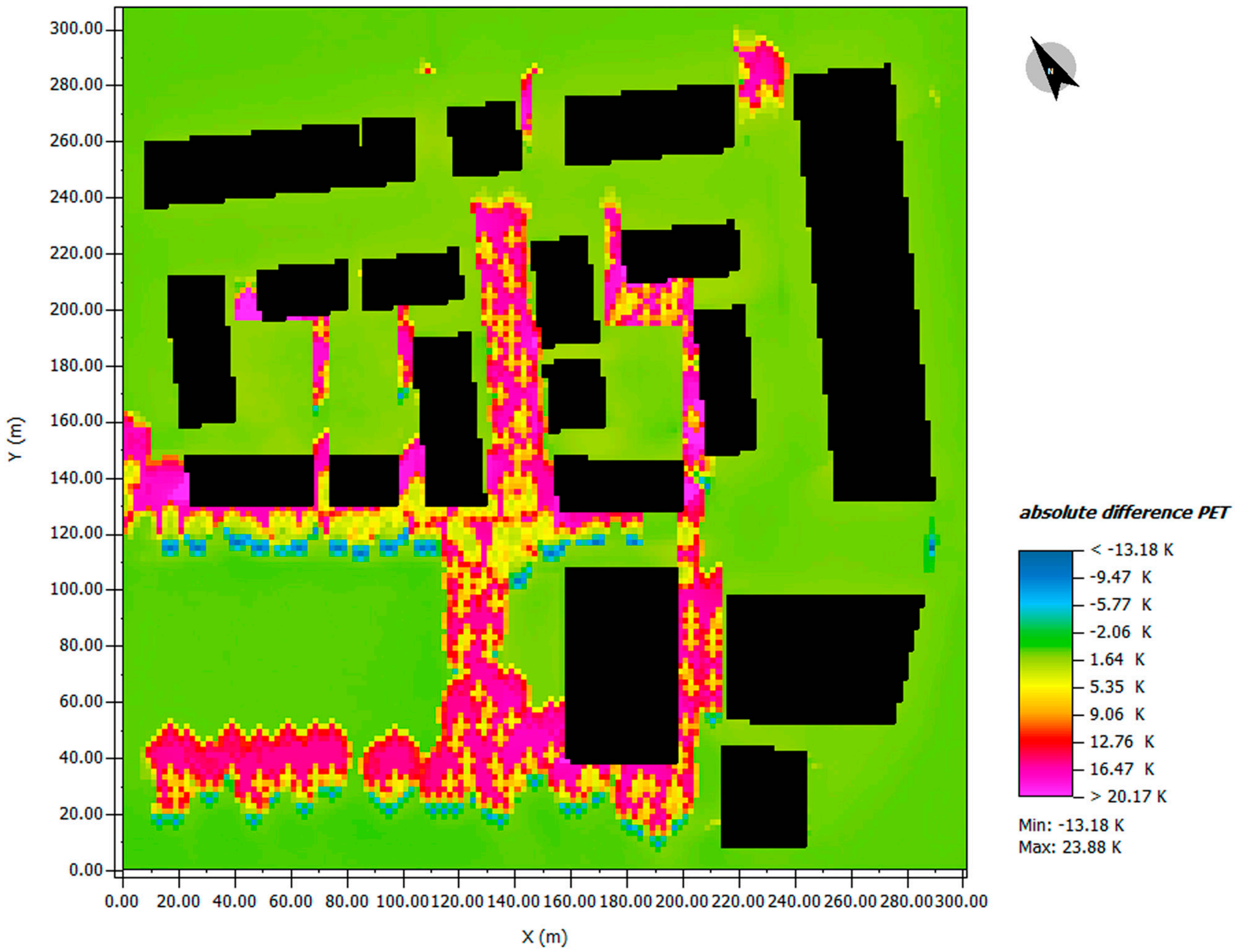


Figure 52. Absolute difference of the PET values (K) at 14:00 hours, from the two simulated scenarios (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

Figure 49 (opposite page, top). Comparison of Facade Surface Temperatures at 11:00 hours, before (left) and after (right) adaptation measures (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

Figure 50 (opposite page, center). Comparison of Ground Surface Temperatures at 15:00 hours, before (left) and after (right) adaptation measures (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

Figure 51 (opposite page, bottom). Comparison of PET values at 13:00 hours before (left) and after (right) adaptation measures (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

Chapter 6

Findings and Discussion

This chapter is dedicated to the review of the results obtained from the methodological process, in order to synthesize the relevance of the outcome in relation to the posed questions of this study. In this sense, the research questions will be once again outlined, to understand how they have been answered and how the resulted findings raise conclusions in the form of specific and general recommendations. The diagram in Figure 53 illustrates the resulted outcome of this research.

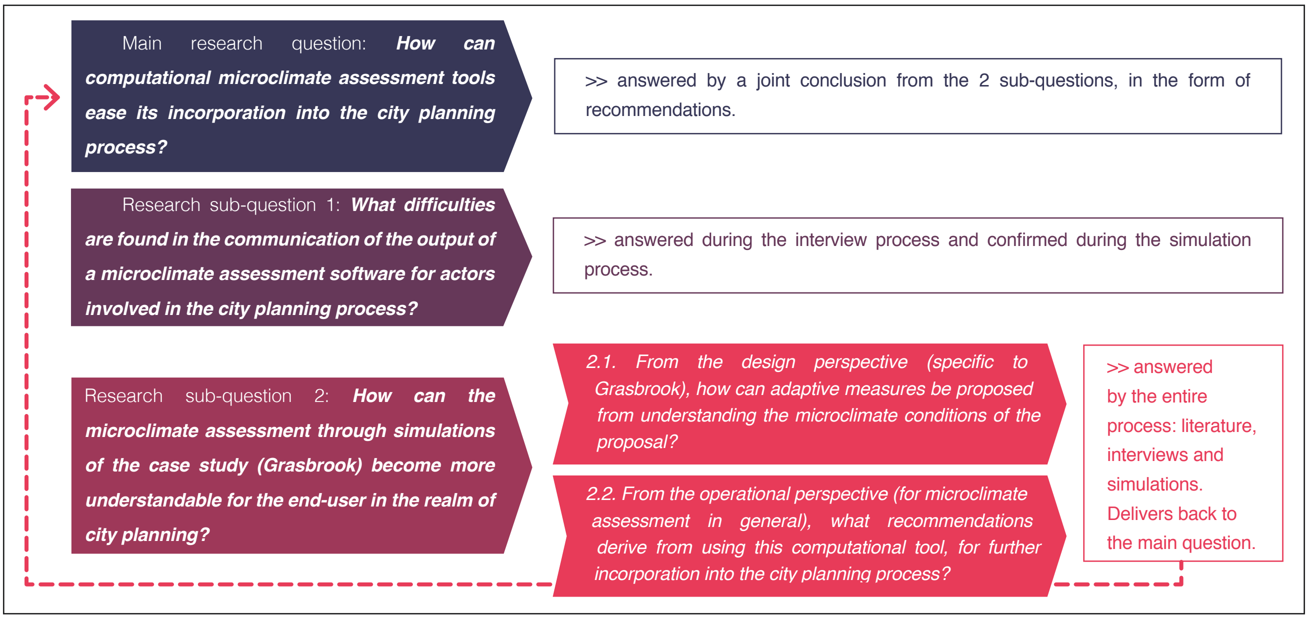


Figure 53. Diagram explaining the outcome of the research questions (author, 2021).

The main research question is answered by a joint conclusion from the two complementing sub-questions, explained at the end of this chapter. To better understand the outcome of the two research sub-questions which support the main research question, their respective findings are detailed below.

6.1. Findings related to the first research sub-question.

In the case of the first sub-question, the topic of difficulties found in the communication of the output data when performing computational simulations was mostly addressed by the interview phase of the methodology. The findings from the interview process were further supported by the empirical phase of the case study simulations. In order to synthesize the content resulting from the Interview process, an adaptation from a problem-to-objective tree scheme was implemented on the Thematic Content Analysis. This helped to translate the gathered statements into positive recommendations. The result can be seen in detail in Table 08 and it is supported by the content in Annex A5.

One of the most relevant findings is related to the fact that digital simulations are not entirely computer-driven processes and that the human-related aspects affect greatly the outcome of a successful microclimate assessment. In this

Figure 54 (opposite page). 3D view of wind flow in Grasbrook Envi-Met simulation (author, 2021).
Note: Taken from *Envi-Met (4.4.3.) [Computer software]*, by Envi-Met, 2020.
Copyright 2021 by Envi-Met GmbH.

THEMES >>	SUB-THEMES	FROM CONCLUSIONS >>	>	TO RECOMMENDATIONS
APPLICATION	Analog vs Digital	On-site assessment is still fundamental. On-site assessment should be a first step before simulations. An expert on site will always be more accurate than a simulation.	>	Optimize exchange or complement between onsite and simulation assessment for microclimate. Prevent that simulations take over the indispensable task of onsite assessment.
	When is it indispensable to use simulations?	For Indoor / Outdoor assessment. If 2 seasons-scenarios are too far appart timewise to evaluate. If the area is too complex. For unknown future scenarios. To compare existing versus proposed. If the area is not accessible or too far.	>	Simulations in comparison to on-site assessments, are an advantegous tool for: indoor/outdoor, complex areas, international areas, unbuilt scenarios, extreme seasons difference, scenario comparison.
	The Goal: what is it done for?	The client usually sets the request. So the goal is determined by the client. The goal, or why is it studied, should be known from the start. The assessment could be done for design, for assessment or for guidelines purposes.	>	Define from the start with the client the goal of the task, before considering if simulations are needed. Determine if the task is requested for: design, assessment or guidelines purposes.
WORKFLOW	Best stage of projects to perform a microclimate assessment?	At the beginning is optimal but in all stages is possible. Later is more costly.	>	Adapt to which stage of the project the simulation is requested: Beginning / Concept Phase: Less is defined, so more can be determined, but too many variables are open. Intermediate / Development Phase: Possibility for iteration in the planning. End / Detail Phase: More is defined, but still materials can be determined. Late decisions will cost more for the overall project.
	Who performs simulations?	In general, specialized people who usually do not come into play for the other phases of projects. Not enough integration, but more focused.	>	Notions if urban planning are important, but also expertise in climate and physics. Data knowledge is becoming relevant and indispensable. More integration between the tool user and the other areas of the development process must be reinforced.
	Team workflow for microclimate	Knowledge and communication is needed. Iterative processes between planning offices, architecture firms and consultancy is crucial. At least one person knowing the project along its entire process. When the approach is as planners, all variables must be tackled simultaneously.	>	Knowledge and communication is of upmost importance. Constant iterative exchange between planning office, architecture firm and consultancy should be done. One person hovering constantly over all groups and stages of the project.
HURDLES	Time resource / computer power	Extensive computer-time is a problem. Software limitations when a client wants quick answers.	>	Software improvements needed: less time consumption for simulations, simplofy the coplexity between large areas and grid scale. Differentiate between a detailed and a simpler model, depending on the request. Develop a simpler model for the case of clients with time constraints. To counteract human hurdles: Simplify the human task of selecting adequate data. Increase the quality and availability of data in cities.
	Scale vs range	The calibration between the adequate scale and range of a project area is difficult.		
	Input data	Human dedication during the selection and cleaning of input data.		
	Expectations of results	Human interpretation is still an important factor after simulations. Expertise and excepticism are necessary skills to read results. Understand a simulation as an approximation to reality but not reality itself.	>	Educate further on how to interpret results from simulations. Share expertise and perspectives among the different disciplines involved in simulations and communication of results.
OUTPUT	Target: what is assessed?	Urban Heat Island, Energy Performance, Climate Adaptation, Human Thermal Comfort, Pollution and Health. A more holistic view on the targets is necessary not only invidiual parameters.	>	An effort should be made towards aiming at a more holistic view across different ecosystems, beyond solely the human scope of microclimate. It is not recommended to focus on one single target and its parameters to address sustainability problems.
	Precision	A simulation will not be as precise as reality, but it is not the intention. The results should be interpreted, the trend and perspective of the output.	>	Imprecision should be accepted when performing simulations. Acknowledge it is an approximation to reality and read the tendency.
REPRESENTATION	Translation, decoding, additional tools	Plug-ins to software are becoming more relevant. 3D visuals are useful for non-experts. Usually results are destined for non-experts, who need the content translated or simplified.	>	Instead of considering a single digital tool, promote the variety of available plug-ins and tools, understanding their advantage in each case. Increase the use of 3D visuals for results.
COMMUNICATION		How to simplify content without banalizing it, is a human, interpretation step. Communicating results is a human task. Comunicating results is a teaching process, along a chain of stakeholders, so content must be clear to go all the way. Consensus must be achieved for clear decision-making.	>	Acknowledge that communicating results is a crucial time-demanding human process. The content should be clear for all types of recipients, in order to guarantee good communication along the chain of stakeholders and reach consensus. Communicating results should be made with an educational approach for a non-expert recipient.
THE CLIENT / END-USER		The client is varied. It is usually a non-expert on microclimate. It sets the goal, makes the final decisions and sets the pace of the task.	>	Request from the client from the beginning to define: the field of applicability of the assessment, the purpose of the study requested, timeframe for the delivery of solutions, his or her background and level of understanding on the topic.
FUTURE DEVELOPMENT		Simulate more future scenarios, involve health data, abilitate more urban measurement data, develop faster or simpler software, perform more studies on green facades, assess more indoor/outdoor. broaden the scope and involve other ecosystems.	>	In the coming years for microclimate development: Look into the realm of public health. Broaden the scope across multiple ecosystems andnot only the human environment. Simulate more future scenarios. Look into indoor/outdoor symbiosis. Look into the impact of Green Facades and evapotranspiration.

sense, recommendations which imply human decisions within the process and should be considered to achieve good communication of the results involve: complement properly the analog and digital processes of microclimate assessments, depending on what each one can provide as advantages in each situation; clarify with the client from the beginning the purpose, targets and scope of the assessment; adapt to which stage of the project the assessment is being requested; pursue iterative check-ups along the entire process; and secure more interdisciplinary integration between involved actors.

Another important barrier found during the gathered content from interviews relates to the expectations of results and the underestimated task of analyzing the results for further communication to the end-user. In this regard, it is recommended that educational tasks on how to interpret the results should be implemented, this could be partly achieved by sharing the attained expertise from each of the different disciplines involved in the use of simulation tools and in the communication of results.

This topic links further to the following activity of communicating the results after analysis, and relates to the recipient of the information or end-user, who might not have the required expertise on the subject. So, the communication of the content should also be done with an educational approach, to guarantee successful delivery and consensus. An additional support to the delivery of results, has to do with the acknowledgement of the multiple open-access plug-in tools, going beyond the use of one single software such as Envi-Met. This can contribute to the better translation of the output content into the proper means of representation, depending on each case.

6.2. Findings related to the second research sub-question.

Regarding the findings for the second sub-question, the purpose behind the microclimate computational simulation was two-fold: to understand what recommendations from a design perspective for the Grasbrook proposal can result from the digital simulation and also to provide specific recommendations on how to improve the use of digital tools from a operational perspective. This two-fold approach should give additional insights which were not found in the first sub-question and conclude by delivering back to the main research question of the study, with holistic recommendations on how to enhance microclimate assessment in city planning.

6.2.1. Recommendations from the design perspective.

The simulation process evidenced that iteration is an indispensable part of microclimate assessment. This was previously discussed with the experts

Table 08 (opposite page). Resulting recommendations from the interviews thematic content analysis gathered conclusions (author, 2021).

during the interview process, and then supported by the empirical process of the Grasbrook study. It was necessary to visualize a first set of results, to gather a set of adaptive measures, which needed then to be tested on a subsequent simulation process.

The results related to the complex dynamics of thermal comfort are definitely better understood when visualized in the form of maps. The barriers discussed with experts, related to the human-step of analyzing the results, was corroborated when reaching the analysis phase of the first results from the case study simulation, which was indeed time demanding. It can therefore be strengthened that digital simulations are not uniquely computer processes.

On the other hand, it can also be said that the simulation revealed aspects shaping the urban form which could be enhanced from the perspective of microclimate, and which would have otherwise perhaps been overlooked in a traditional urban design process. Thanks to the digital simulation assessment, values related to ground and surface temperature, vegetation canopies and the effect of façade greenings were visually understood and could be better calibrated in order to achieve appropriate Human Thermal Comfort levels for the case of Grasbrook. From this, it can be understood that visualizing parameters affecting the PET values at neighborhood scale in a simultaneous way is something beyond what an analog assessment could do.

In this sense, the PET values were not improved individually, but as a result of the alteration of other parameters of the local climate presented in the model. The value of the achieved results relate to their capacity to translate not only the correlation between elements from the urban form which affect Outdoor Thermal Comfort, but also illustrates how can it be enhanced through proper calibration of various urban design considerations simultaneously.

6.2.2. Recommendations from the operational perspective.

In regards to the experience of using Envi-Met as a computational simulation tool for microclimate, a series of recommendations can be gathered. These observations arise from the setbacks during the empirical process of performing simulations and its further representation for communicating purposes.

Regarding Interdisciplinary Expertise: The time dedication to understand and analyze the microclimate output could have been reduced if working alongside a microclimate expert. On the other hand, to have a background in the field of architecture and understanding urban notions was helpful to analyze the results within the urban fabric. As discussed during the interview chapter, in regards to the topic of relevant knowledge to assess microclimate with computational tools, it was argued that sometimes the architectural background is a counterpart needed to complement expertise for the microclimate assessment. In this sense, an interdisciplinary exchange could contribute to a faster and deeper analysis of the situation.

Regarding the Interface: As explained in Chapter 5, the use of a computational desktop software such as Envi-Met implies extended time dedication to produce its output in the form of maps and 3D views. Once this process is finished, the resulted maps can be shown and discussed with the relevant actors of the decision-making process. Nevertheless, in order to obtain a more effective interdisciplinary exchange among the relevant stakeholders of a city planning process, a more hands-on interface tool could be needed, where iteration processes for different scenarios can be performed and reviewed in a faster and more direct way. This would also enhance a more active participation and understanding of the variables affecting microclimate on behalf of many of the decision-makers, instead of incorporating them at the last phase of the microclimate assessment, when the results have already been produced.

Regarding Time-Span: The selection of a single date before running a simulation implies a decision process which leaves many other situations out of the overview. This raises new questions, for which scenario should one plan cities? How to select the most dramatic scenario? After reviewing the output of the software in the Leonardo program, it seems fundamental to have a look into multiple times of the year and not in one single day. Even more so, when the results of one-single day simulation are to be reviewed, it also seems necessary to see this in timeframes because otherwise the peaks of a specific phenomenon cannot really be observed. This is something which is not directly done by the software, and implied further work, to produce hourly maps and put them together in order to see a 24-hour timespan of the different factors which are of interest.

Regarding the Multiple Dimensions of Microclimate: The outcome of the microclimate assessment should not only refer to the physical dimension of the urban form, in terms of shape, materials and vegetation, but should also overlap with other types of assessments referring to the dynamic aspects of urban life like mobility and activities. The knowledge resulted from microclimate topics such as Outdoor Thermal Comfort, can broaden the possibilities of what can be enhanced in the use of the urban open spaces. This is a direct advantage which should be considered to consolidate its incorporation into the City Planning process. Future cities should extend the use of microclimate assessments to plan the adequacy of different activities in a time and location-bound manner. Figure 55 ilustrates a vision of how the overlapping of microclimate with the use of the urban space, could actively shape the dynamics of cities for greater human comfort, when the questions asked are: what can happen, when and where?

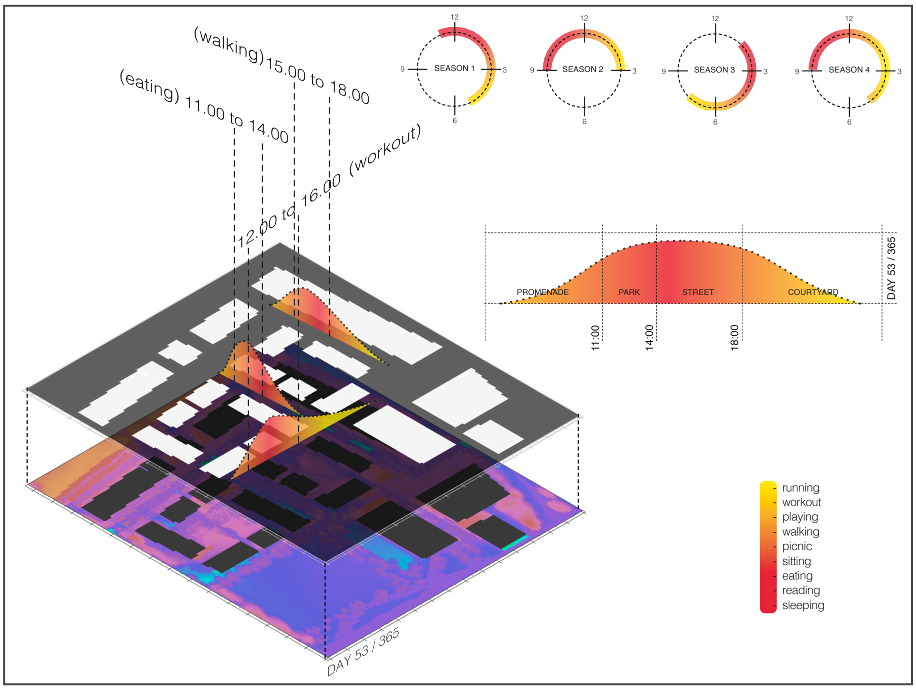


Figure 55. Schematic vision of future microclimate assessments (author, 2021).

The recommendations gathered in this study from the operational perspective of how future microclimate assessment should be envisioned, are in line with the sought out development pursued by the online platform tool from the DCS group, the Cityscope. In their latest publication, the authors explain their future objectives based on current experiences related to city planning processes, and within this plan, the scope of microclimate is intended to be included. "Reaching beyond performance assessments of physical and spatial-morphological properties, future editions of the CityScope shall also provide modules for the analysis of human interaction and social dynamics in urban environments" (López Baeza et al., 2021).

6.3. Assumptions and Limitations of the Study

The following assumptions and limitations affect the outcome of this study.

General assumptions: Grasbrook was a relevant case study to address the topic of microclimate and the proposed research questions.

The topic for this research could be addressed by using only one software related to microclimate, after reviewing through literature that Envi-Met is one of the most widely used.

The amount and type of selected experts for the interviews provided a sufficiently broad overview on the topic.

The acquired knowledge on microclimate topics on behalf of the researcher of this study was enough to analyze the results from the simulations.

Assumptions during simulations: For both simulation scenarios performed, the level of complexity defined at Beginner level in the simulation settings provides enough insight on the digital assessment to gather relevant conclusions.

The selected output maps in the Leonardo sub-program from Envi-Met, were enough for the topic addressed and the case study selected, despite having Leonardo a broader possibility of maps to be produced.

General limitations: The amount of experts interviewed was limited because of availability or time constraints. Originally, ten experts were contacted for interviews.

The acquired knowledge on the topic of microclimate was gathered mostly through literature review and through the process of the experts interviews. There could be limitations to the depths of this analysis, partly hindered by the researcher's background from the field of architecture.

The entire area of Grasbrook was not assessed due to the time consumption demanded by the selected software in comparison to the available time for the empirical phase of this thesis.

Elements defining the urban characteristics of the case study are based on the available information from the website of the Grasbrook Competition. There is a margin of interpretation in the selection of materials, vegetation types when assembling the spatial model for the simulation. This is partly due to the fact that the study focuses on an urban area which is still under a design process, and not a completely built area.

Limitations during simulations: The accuracy of the output data shown towards the edges of an Envi-Met spatial model are not yet completely reliable due to the nature of this physical model, and therefore microclimate situations shown at the perimeter cells should be disregarded (*Nesting Grids*, 2018).

The characteristics of the materials and vegetation types are set by the predefined catalog from the Envi-Met software. This study relies on the accuracy of the physical properties defined by Envi-Met in its System Database.

Chapter 7

Conclusions

The incentive for this study was originally driven by the need to review our current methods to address the planning of cities, given the historical evidence that cities' reforms have periodically happened in close relation to health-related and sanitary crises. The pandemic of covid-19 served as a wakeup call to make evident that health and cities are bound to human activity. It should be considered as a turning point to seek which type of development must society turn to. It is now ever more relevant to take advantage of innovative digital approaches to bring closer microclimate to the planning of cities, pushing forward the incorporation of data as an important societal asset.

This research aimed to understand the impact of computational tools on the enhancement of the microclimate in the open spaces of cities, and how can this be more efficiently included into city planning processes. To achieve this research goal, two main objectives were set, the first related to the barriers found in the communication of the output resulting from digital simulation processes, and a subsequent objective referring to the understanding of how microclimate digital assessment can become more understandable for its end user. Beyond the already found hurdles in the literature review regarding computer-power and time-consumption, new findings were revealed through the applied quantitative and qualitative methodology. Results from the first part of the methodological approach, show that besides the computer-related aspects, human input along the process also affect greatly the outcome of a successful microclimate assessment. It was therefore concluded that proper analysis, iteration, communication and representation are all important human steps, which condition the achievement of successful results towards decision-making.

The empirical part of the methodology, served to look more in-depth into this first conclusion statement. Relevant reflections were also concluded, related in this case to the technical aspects of the computer simulation. Grasbrook, as a case study, served the purpose of putting into practice the input taken from the interview methodology. The specific study of the Grasbrook case revealed that indeed, performing a simulation allowed to understand other parameters which affect the open space, this time from the perspective of the microclimate and which would have otherwise been difficult to assess prior to construction. This can give planners the possibility to reconsider decisions which can still be curbed along the remaining process of this urban development, and reduce in the long term cost-inefficient consequences.

Besides providing a series of specific design recommendations for the enhancement of the new district, the results evidenced how certain operational

Figure 56 (opposite page). Grasbrook Park at HafenCity (own photo, 2020).

steps could also be improved in order to optimize its incorporation in the general planning process. The simulations showed that expertise related to fields such as meteorology and physics were not the only ones necessary for a thorough analysis of the output, but also urban-related notions are indispensable to formulate solutions. This issue was previously addressed during the literature overview and the interview procedures, and could be finally experienced in detail during the empirical phase, strengthening the idea that in many cases they do not seem to be connected and a transdisciplinary approach to engage better in city planning is indeed necessary.

Further findings related to the operational interface to which some of these microclimate simulation programs are bound to, such as desktop software, evidence the limited interaction among the different actors involved in the entire process. An entire desktop simulation process is normally undertaken by one user, assuming a series of human-driven decisions, to finally deliver synthesized results to its other multiple end-users. This extensive process limits the possibility to reach consensus by means of iteration, verification and discussion among many, along its course. In this sense, a valuable conclusion relates to the need of also pursuing a different kind of interface, as hands-on tool which could significantly reduce the time dedicated to the translation of results or the iteration processes, therefore arriving faster to the consensus phase of planning. The possibility to redefine a microclimate assessment tool could also contribute to the assessment of multiple scenarios, in a more time-efficient manner, as it was evidenced by the experience of analyzing the microclimate of Grasbrook, that indeed only one instant of an entire year-time was looked into with detail. These conclusions, when put into practice, should focus on the development of a more interactive tool which could greatly contribute to diminish the time consuming barriers related to interdisciplinarity, communication, iteration and representation; enhancing in this way overall better exchange towards consensus for planning.

Based on the outcome of this methodology, specific and general recommendations can also be outlined in regards to potential future research related to the topic. Regarding the case of the Grasbrook New District proposal, further studies could address not only microclimate from the perspective of thermal comfort in outdoor spaces, but also related to the impact of the energy performance of the district. This target is out of the scope of this study, but it is nevertheless of great value, because of its contribution to sustainable measures, not only in the mitigating sense, but focusing more on a regenerative approach, opening possibilities to provide positive impacts on Grasbrook.

Additional and more general recommendations towards where microclimate research can look into for future development, can be, for example, its synchronization with public health data as an opportunity to address matters related to urban health in cities. Also, deeper study on the impact generated by Urban Green Infrastructure, such as green facades, or vegetation canopies shows still space for further research related to comfort levels. As cities become more dense and complex, the necessity to assess indoor and outdoor symbiotic exchange or possible future scenarios will also become more demanded, and simulations should be able to provide results in a timely manner. Ultimately, broadening its scope across multiple ecosystems, instead of limiting the focus to the human activity, resulted as recommendation from part of the methodology process, and should be considered, given the clear coexistence of multiple ecosystems across urban settlements.

A final contribution, from the gathered findings among all steps of the methodology for this study, reflects upon the advantages that result from linking the effects of microclimate to other parameters impacting the urban dwelling of open spaces, for it to give useful insights into the city planning realm. Understanding how climate conditions other dynamics, such as social activities related to land-use type or open spaces typologies, and how they constantly change along an entire day or throughout seasons, can push forward city planning into another dimension of sustainable living.

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Annex

Annex A - Interview procedure

Annex B - Field Measurements

Annex C - Material for Envi-Met User Database

ANNEX A – Interview procedure

A1 - Explanatory Statement

A2 - Consent Form

A3 - Interview Protocol

A4 - Thematic Content Map on digital whiteboard (MiroBoard)

(for consultation of the transcription of the interviews, please contact the author)

ANNEX - A1

Institution: HafenCity University Hamburg – University of the Built Environment and Metropolitan Development (HCU)

Master Programme: Resource Efficiency in Architecture and Planning (REAP - M.Sc.)

Title of Master Thesis: Impact of Digital Planning Tools on the enhancement of Urban Microclimate. Case study: Grasbrook District (Hamburg).

Student: María Moleiro Dale

HCU Supervisors: Prof. Dr.-Ing. Wolfgang Dickhaut / Dr. Angeliki Chatzidimitriou

EXPLANATORY STATEMENT

You are invited to take part in this Master Thesis project. Please read the Explanatory Statement for an understanding of this research before deciding whether or not to participate. If you have any questions or would like further information, please contact me at: maria.dale@hcu-hamburg.de

What does the research involve?

The starting point for this research is based on the need to question the future of city planning, especially as we consolidate an Era of digital processes. The open space in cities remains the common ground of the urban realm where diversity happens and also where microclimatic conditions are mostly exacerbated.

The aim of my study is to understand how digital tools implemented for city planning can contribute to the improvement of microclimate conditions for urban environments. More specifically, how user-friendly are the interfaces of such digital tools for microclimate assessment, and for whom are they ultimately designed to be efficiently implemented and understood.

You are invited to participate in a semi-structured interview. The interview will last approximately 45 minutes. Questions will be based upon the following topics:

- Workflow, related to microclimate assessment.
- Microclimate assessment through simulation processes.
- Decision-making stage of the process.

Why were you chosen for this research?

You are a practitioner and/ or have experience on projects relating to the assessment of microclimate conditions in urban areas. You would have been contacted directly by myself or through your colleague, who would have recommended you to be part of this project.

Consenting to participate in the project and withdrawing from the research

Before the commencement of the interview or questionnaire, you will be asked to sign a consent form. You have the right to withdraw from further participation at any stage. It will not be possible to withdraw the answers given after the interview.

Possible benefits and risks to participants

The findings of this research will translate into a series of recommendations for the optimization of the represented microclimate output data in the form of results for its final user. Ultimately, achieving proper calibration of microclimatic conditions in an urban environment can contribute to goals such as more efficient urban planning processes and thus optimal use of the common open spaces of cities. This research does not put you at any personal risk and will only require some of your time.

Confidentiality and storage of data

Any data collected during this research will be treated confidentially. Interviews will be recorded and transcribed, and direct quotes will only be used with consent of participants. No personal details will be shared with any third party at any time.

ANNEX - A2

Institution: HafenCity University Hamburg – University of the Built Environment and Metropolitan Development (HCU)

Master Programme: Resource Efficiency in Architecture and Planning (REAP - M.Sc.)

Title of Master Thesis: Impact of Digital Planning Tools on the enhancement of Urban Microclimate. Case study: Grasbrook District (Hamburg).

Student: María Moleiro Dale

HCU Supervisors: Prof. Dr.-Ing. Wolfgang Dickhaut / Dr. Angeliki Chatzidimitriou

CONSENT FORM

You are invited to participate in the Master Thesis as stated above. Please read the Explanatory Statement and indicate your consent for the following:

	YES	NO
- Taking part in a semi-structured interview.	O	O
- Audio recording during a semi-structured interview.	O	O
- Any brief follow-up conversations by telephone/ or email for clarification of answers in the interview.	O	O
- Data provided during this research will be used for this project. (Any direct quotations will be previously consented to over email.)	O	O
- Future research could be built upon the data provided to this project.	O	O
- Contact details for further involvement in this project.	O	O

Preferred Contact Details

Name:

Email address:

Phone:

Participant Signature:

Date:

ANNEX - A3

INTERVIEW PROTOCOL

WORKFLOW, RELATED TO MICROCLIMATE ASSESSMENT.

1. Before considering digital tools (such as for example, *Envimet*) to assess the microclimate aspects of your projects, did your team consider any other means of understanding microclimate for the cases studied? Maybe explain why was the use of software considered?
2. Since microclimate digital tools were incorporated into the process of your practice, how often would you say it is used in the projects that you have undertaken? This could be a rough estimate, for example, in about half of the projects, in most of the last projects in the last 2 years?
3. Usually in your working team, what is the profession or level of specialization of the person responsible for the execution of the microclimate assessment software (student, professional or outsourcing, and which field of expertise)?
4. In what stage of your projects have these type of software been usually consulted? Whether it is at a conceptual preliminary phase, development or detail-level phase of the projects? Which has been the learning experience from this?

MICROCLIMATE ASSESSMENT THROUGH SIMULATION PROCESSES.

5. If we break down an entire microclimate assessment process through softwares, between: modelling, simulation, output and analysis phases; in which stage would you consider the greatest hurdles are encountered? Can you describe the type of hurdles found, things such as limitations in the options which can be selected from the predetermined aspects of the software?
6. Is it attainable how much information one can set up, produce and visualize out of the output data, and in your opinion can it all be produced timely, in order to reach the decision making phase?
7. How exact are the results of a simulation? What are the main uncertainty factors? How would you recommend minimizing imprecision?
8. How do you usually handle the data to be used? Whether it is System Database or User Database? Which are most sensible to influence the result?

DECISION-MAKING STAGE OF THE PROCESS.

9. Would you say that the results obtained are used for internal decision-making among the team, or is it also something shown to the potential client? What has been the feedback on the other end when explaining the output content to the client?
10. In your experience, has there been any need to incorporate an additional tool to go from the results obtained through Envimet to the showcase of the information to a client or to the decision-making group? Things like additional softwares, the need to bring in extra human resources with any specialty, or more time dedication at this point of the projects than expected?
11. Was there a specific Target to address when assessing microclimate in your projects? If so, what were the relevant parameters for this?
12. After the attained experience from understanding microclimate in the projects undertaken, could you say there is still the need to understand or reflect one aspect of your projects in a better way than that achieved up to now?

ANNEX - A4

INTERNAL WORKFLOW

1. Before considering digital tools, did your team consider any other means of understanding microclimate for the cases studied? Maybe explain why was the use of software considered?

NABONI: More important than the simulation, is actually to go and sit on site.

NABONI: Sometimes, simulation might not be needed, after onsite.

KATZSCHNER: First understand the site (measurements, experiments, data). Then tools. simulations come later.

TSOKA: First on site measurements (temp./humid) to validate then the model. Always then model.

DIETRICH: The diverse physical phenomena is complex to describe for humans, thats why we are concentrating on simulations.

CAASE: They work directly with the 2 software developed by their own company. They do take field measurements to validate their software.

ANTEROLA: Always determine first the Goal. Typically they do not do on site assessment, although there are many options. But they use directly software, sometimes due to location of projects (foreign).

NABONI: understanding scale, unperceivable factors and the physiological aspect of climate.

DIETRICH: factors affecting an individual onsite: different temperatures, solar radiation, wind, shadows, impact of the shadow of a tree, and so on. Too many, too complex. We turn to simulations.

DIETRICH: hurdle from Envimet, it cannot describe a dynamic situation over time, you investigate a moment but not a movie.

ANTEROLA: Some analog tools to go onsite: Transsolar (about people's comfort feel through backpacks), or Crowdsourcing, citizen participation (i-resilience).

ANTEROLA: Software has 2 levels of complexity: rough estimates for fast solutions and precise results for optimized solutions. But usually in the case of Envimet, the trouble is it is so sophisticated, its too hard for stakeholders who want first quick answers. Ramboll is trying to fill this gap.

ANTEROLA: The goal depends on who the client is and what he wants. That varies from city government and project developers. The goal and the means have to match.

2. How often would you say McS are used in the projects that you have undertaken?

NABONI: This depends on the type of project. If you can catch a hot and a cold day, its better than simulations.

NABONI: Simulations are needed if: the client has a specific request, if there are special configurations planned, or if the thermodynamic interaction of indoor/outdoor is relevant. Simulations are not needed for outdoor only.

KATZSCHNER: Depends. First we divide projects among scale: meso and micro-climate. If the area is not too complex, we never use the digital tools. They are not used in every case.

TSOKA: half of the projects is related to a microclimate analysis.

DIETRICH: Not so often. But depends on what you want to find out: existing situation vs prognosis / unkown future outcome / validating the model against street measurements.

CAASE: Between the wind and microclimate dept is independent, so cant say how often, but in general microclimate is becoming more and more relevant to assess at city level. Cities want to know.

ANTEROLA: In the last 5 years it has taken on more precedence. Goes in hand with the development of better tools lately.

NABONI: if it is for a master plan or general layout, its faster to measure on site. But you need a HOT and a COLD day. When you can do both, this is better than simulations.

NABONI: simulations are efficient, but also time and energy consuming.

ANTEROLA: Still microclimate assessed by architects is still limited more to BUILDING simulations, because the landscape is affected by too many factors. A building environment is closed and controlled. Easier to grasp.

ANTEROLA: Microclimate at LANDSCAPE scale: you have location, topography, seasons, and to understand all these variables you have many different methods. It is not unified.

ANTEROLA: on TOOL: Rhino and Grasshopper. Quick prognosis, for a designer.

ANTEROLA: on TOOL: architects and meteorologists use different tools because its different views.

ANTEROLA: on the importance of bringing different stakeholders together. You need to reach a CONSENSUS. For this, you seek the appropriate tools, and also depending on what the client wants, and what is the goal set. It can be very different.

ANTEROLA: on STAKEHOLDERS: the circle of stakeholders extends further, and you must educate to pass the message further. City gov does not have time to run simulations, they want fast answers, to know what to do.

3. Usually in your working team, what is the profession or level of specialization of the person responsible for the execution of the McS (microclimate assessment software)?

NABONI: Usually architects perform this. Sometimes with meteorologists, they relate better to the larger scale and macro dynamics.

KATZSCHNER: Meteorologists, urban planners. All specialized in GIS. No students.

TSOKA: Not many use the software, only civil engineers. But many do understand the output (in the team).

DIETRICH: It is not direct in his field of research, but generally it is him, so Building Physics, and architecture students.

CAASE: Most are from Environmental Science background, geography or meteorology. It is fundamental for us to have environmental and physics understanding to work on this.

ANTEROLA: These tools should be made for who designs, so architects and planners. But Ramboll also has a dept for complex CFD models, handled by PhD level physics and trainees. This is a specialized team who doesnt come directly into the planning because it doesnt reach an overall view of the project.

CAASE: It would be also useful to have architectural background knowledge in the group to understand further when doing assessment of cities.

ANTEROLA: Within his team, he is developing an easier interface to deliver proper info, at proper time, to know results faster. (green scenario). 3D and not pretty but useful.

4. In what stage of your projects have these type of software been usually consulted? Whether it is at a conceptual preliminary phase, development or detail-level phase of the projects? Which has been the learning experience from this?

NABONI: Depends on the strategy. From the beginning is useful because is where building form settles. But since material is very relevant, the latest stage where materials are defined, is still a big value to do this. At any point can be done.

KATZSCHNER: At the beginning. They review a first design, and re-discuss. Iterative process between architecture office, city planners and consultancy.

TSOKA: Its an iterative process. We take it into account at the beginning, and come back some time in the middle to see what can be improved.

DIETRICH: Ideally at the beginning, but all stages are interesting and possible.

CAASE: Happy when they get as much detail as possible. Minimum is building and street geometry. The grid with which they work is detailed, so the more the better. But also, early is better because then the measures are taken on time. Iterative is also good to do.

ANTEROLA: In all cases. But optimal is at the beginning. Case 1: requested to optimize design solutions. Case 2: requested to validate if the proposed solution is good, or how to improve (this is not the best, because they come too late, is costly at the end).

KATZSCHNER: They do also existing and future scenarios type-of-projects.

KATZSCHNER: Planning Process in Europe varies among countries. But in Germany is more standardized: there is a master plan or land-use plan and from there the design is made. The are national laws and building Codes and regional planning.

ANTEROLA: Usual assessment process order: traffic / parking / green space / open space / landscape / water mgmt / microclimate.

SIMULATION PROCESSES

5. If we break down an entire McS process between: modelling, simulation, output and analysis phases; in which stage would you consider the greatest hurdles are encountered? Can you describe the type of hurdles found?

NABONI: In the geometry making (model). Also the long computational time (simulation).

KATZSCHNER: The input data needs to be good. (buildings, services, materials). So, for model.

TSOKA: Always the modelling. Its a hurdle to find the correct input boundary conditions. If not correct, you find errors in the validation process, before beginning simulation.

DIETRICH: Output, too many options and to select the right one is a difficult task for students. Also the area you need to cover for correct wind assessment, vs computer power.

CAASE: So good results depend on the input data we get. The longest is selecting the correct input data for the model. Also selecting only one scenario to calculate and show. Which is the worst situation.

ANTEROLA: In all cases. For model: quality of the input data coming in. / Simulation is pretty straightforward / Output and analysis: the communication is the hardest. Explaining the results: what do they mean? how to improve?

KATZSCHNER: About simulations: it is never as reality. It is an approximation to the conditions.

TSOKA: explains the problem with the grid and scale, when there is more detail. She prefers to work, nevertheless with grid than plugins.

6. Is it attainable how much information one can set up, produce and visualize out of the output data, andcan it be done timely, in order to reach the decision making phase?

NABONI: 4 things can happen: the now-what? question / simulation was wrong / results are lame, you knew already what it gives you / it is interesting.

NABONI: Its important to not look only at the numbers, but the tendency , put it in perspective.

KATZSCHNER: Depending on the model: a statistical model is quick. a numerical model is more time-intensive. It is a question of how fast the government needs the decisions (f.e)

TSOKA: You need to calculate the time consumption from the beginning. Plan including error time.

CAASE: Its about communication with the client from the beginning, time management and knowing what the client needs from the beginning.

ANTEROLA: It has to be the goal. To make it on time. You adapt to whether you need quick rough answers, or detailed ones. Depending on the case. And be prepared to go back and give more answers. Change parameters.

NABONI: On interpreting results: acknowledge micro-variations, interpret, find the trend. Not look at numbers but the TREND. Put the numbers in perspective.

7. How exact are the results of a simulation? What are the main uncertainty factors? How would you recommend minimizing imprecision?

NABONI: Every simulation is always wrong, for sure. Its important to go further than the exact number, to get to an understanding of things.

NABONI: Never trust someone who does ONLY simulations, instead of site.

KATZSCHNER: Never rely purely on a numerical model. You need specialized people to interpret the results. Human factor interpretation.

DIETRICH: After waiting long for results, the outcome will be as good as the input that was selected, but one must read carefully the certainty of the results. You need a skeptical view or experience to read properly the results. With the software, one doesnt know what is assumed in the physical model.

CAASE: It is more about finding hotspots than knowing the exact value. Its more about the relativity between different spots of the whole area. But normally our results are pretty close.

ANTEROLA: Having an expert on site will always be more accurate than the simulations. But again, one should ask what is the goal of doing this? for city planning is to find hotspots and improve the plan. For scientists is for something different. Doesnt have to be accurate.

KATZSCHNER: architects directly cannot understand each detail of the microclimate topic. Translation from science is needed. Different languages.

8. How do you usually handle the data to be used? Whether it is System Database or User Database? Which are most sensible to influence the result?

TSOKA: Usually combining both. When possible, I use the most local data available.
CAASE: We use both.

DECISION-MAKING PHASE

9. Are the results obtained used for internal decision-making among the team, or is it also something shown to the potential client? What has been the feedback on the other end when explaining the output content to the client?

NABONI: To show to the client, the results must be simplified or decoded for him to understand the technical aspects. Simplified without banalized.

KATZSCHNER: Two steps: first, internal evaluation. Second, a verbal discussion with clients. Third, we produce the final report.

TSOKA: Usually there is no client because its university research. But when there is, some maps from Leonardo are a bit enhanced to be understood by other background readers.

DIETRICH: We do both. For a Thesis, it is internal use. When it is for the client (city administration, building owners, etc) you make more detailed recommendations.

CAASE: There is usually one person in direct contact with the client along the entire process. If there is a hurdle, they solve this internally among the group. When the info is shown to the client, depending on the client, they might have to simplify or illustrate more the concepts for them to understand.

ANTEROLA: They are shown to the clients, and as a teaching process. They cannot be too complex. The client then, once he understands the meaning behind it, he wants to do more about it.

NABONI: The results to clients are sometimes for assessment, for design, or for guidelines.

NABONI: At this point is important to answer the question: what do we know now that we didn't know before?

10. Has there been any need to incorporate an additional tool to go from the results obtained through Envimet to the showcase of the information to a client or to the decision-making group?

NABONI: Yes, the Grashopper plugin. Helps interpolate key meanings. Simplifies content. Depends who you are talking to.

KATZSCHNER: Normally use climatology tools. And they developed a guideline, a recommendation legend, with fixed formats for maps, legends, ranges.

TSOKA: Automatize receptors data through a Macro file in Excel. Enhancement of shades in Leonardo maps through Sketchup.

DIETRICH: Normally not, with Envimet you have good maps and graphs.

CAASE: Yes because their results come out as text files, they must be converted through any GIS software, to make maps. They do not have but wish to have 3D visuals as well, they find it useful.

ANTEROLA: Graphically no. But content-wise the information has to be broken down more. Still we do the 2 versions: rough and light (quick) and sophisticated, complex, heavy version. But it must be always understood to be approved.

NABONI: It is important not to refer only to the HUMAN comfort, but to acknowledge other species and other ecosystems affected by microclimate.

TSOKA: Works with receptors (as excel files). She created a Macro to automatize this process for each of the 24 hours.

11. Was there a specific Target to address when assessing microclimate in your projects? If so, what were the relevant parameters for this?

NABONI: I use the tool to understand always a series of parameters. Not only related to thermal comfort. the environment hollistically as a medium between the human and the ecosystem. Stop thinking human-centric.

KATZSCHNER: Heat Island / Energy / climate adaptation.

TSOKA: Mainly the effect of Climate on buildings, and their performance. For this: temperature, solar radiation, wind speed, and how these affect convective heat loss. / Also Mean radiant temperature for outdoor thermal comfort.

DIETRICH: Human Thermal Comfort. If the result requires iteration, you must go one step back and read over the situation again, and there you find maybe new parameters affecting comfort.

CAASE: Often for microclimate situation. Wind comfort is also usual, specially close to the coast or water bodies, or with high rise buildings. Also concentration of NO2 emissions (fuel pollution).

ANTEROLA: The big questions are still Thermal Comfort and Urban Heat Island. For us it is so because we are not climate experts, we are planners.

NABONI: The human sustainability paradigma is obsolete. Regenerative approaches are needed. We need to stop thinking human centric.

ANTEROLA: Their approach is as planners, not microclimate experts. So they address microclimate, but also with space, and costs, and handle everything, standing in the middle of all variables of the planning process, to find solutions.

12. Could you say there is still the need to understand or reflect on one aspect of your projects in a better way than that achieved up to now?

NABONI: We need to plug more domains ino the microclimate discourse / work with public health data / pollution related to microclimate / involve other ecosystems (vegetation, other species) / simulate for future-scenarios.

KATZSCHNER: Quicker tools / Also, tools easier to transfer from GIS into climate. / More measurements of cities.

TSOKA: Computational force and simulation time.

DIETRICH: In general the model is well developed. But the impact of green facades is something still to develop.

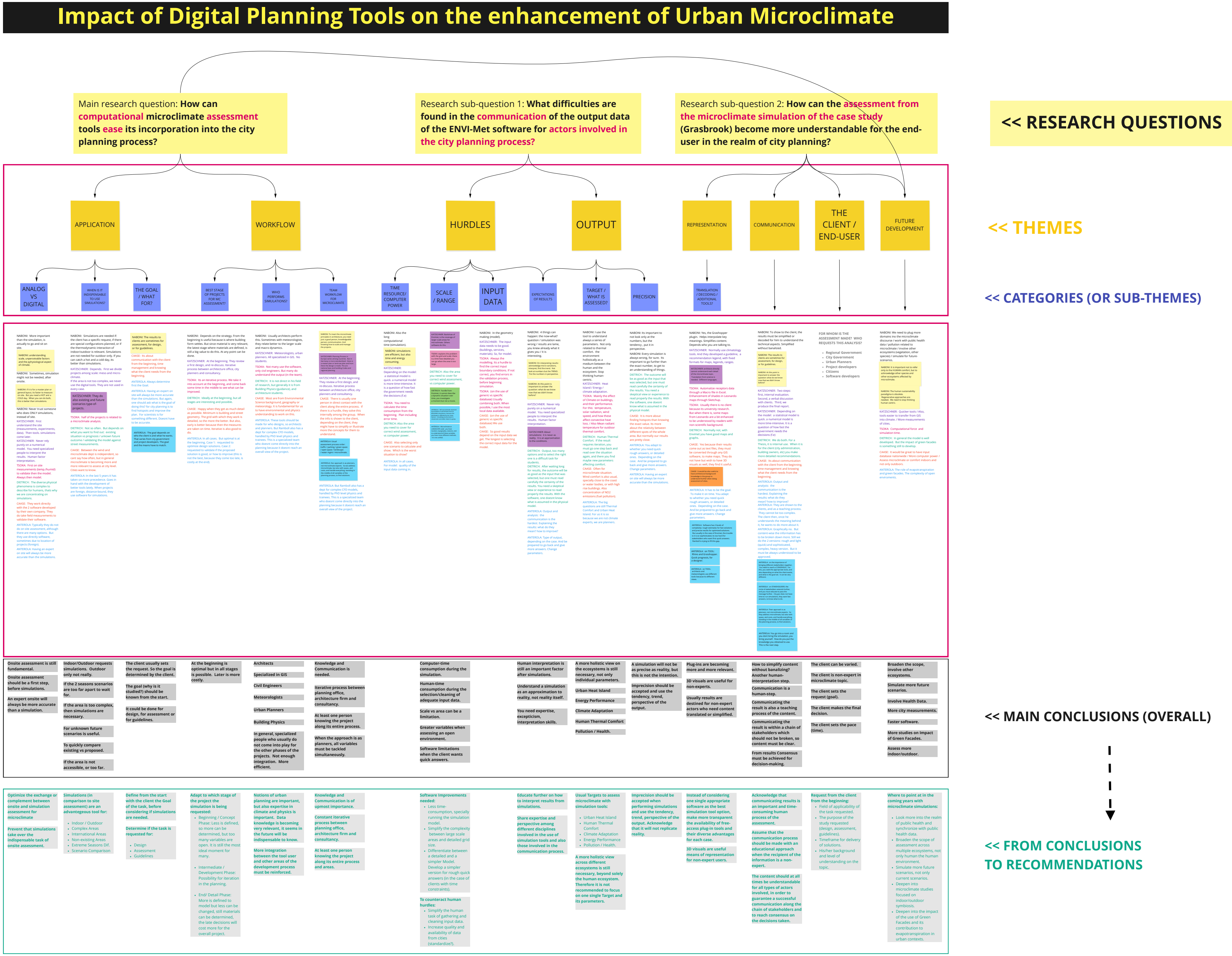
CAASE: It would be great to have input database nationwide / More computer power / Assess microclimate or comfort indoors and not only outdoors.

ANTEROLA: The role of evapotranspiration and green facades. The complexity of open enviroments.

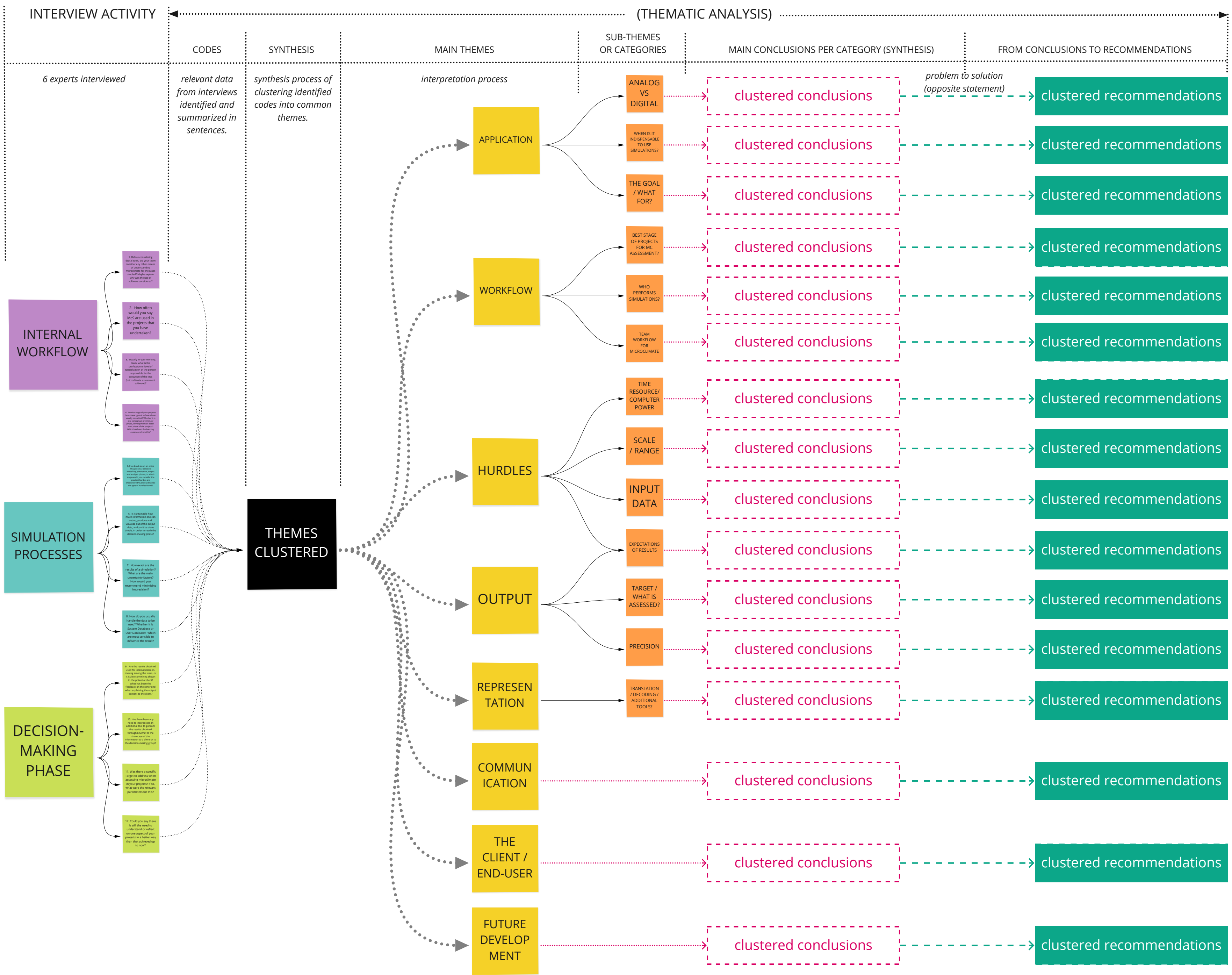
NABONI: To insert the microclimate principles in architecture, you need just: a good person, knowledgeable person, communication. And knowing how to scale and manage the projects.

KATZSCHNER: Backdraw of Envimet, is the coverage of larger scale areas for microclimate. Others software do this.

ANTEROLA: You go into a room and you dont bring the simulation, you bring yourself. How do you put the knowledge you obtained to use. This is the next step.



Impact of Digital Planning Tools on the enhancement of Urban Microclimate
Main research question: How can computational microclimate assessment tools ease its incorporation into the city planning process?
Research sub-question 1: What difficulties are found in the communication of the output data of the ENVI-Met software for actors involved in the city planning process?
Research sub-question 2: How can the assessment from the microclimate simulation of the case study (Grasbrook) become more understandable for the end-user in the realm of city planning?
<< RESEARCH QUESTIONS
APPLICATION
WORKFLOW
HURDLES
OUTPUT
REPRESENTATION
COMMUNICATION
THE CLIENT / END-USER
FUTURE DEVELOPMENT
<< THEMES
ANALOG VS DIGITAL
WHEN IS IT INDISPENSABLE TO USE SIMULATIONS?
THE GOAL / WHAT FOR?
BEST STAGE OF PROJECTS FOR MC ASSESSMENT?
WHO PERFORMS SIMULATIONS?
TEAM WORKFLOW FOR MICROCLIMATE
TIME RESOURCE/ COMPUTER POWER
SCALE / RANGE
INPUT DATA
EXPECTATIONS OF RESULTS
TARGET / WHAT IS ASSESSED?
PRECISION
TRANSLATION / DECODING / ADDITIONAL TOOLS?
<< CATEGORIES (OR SUB-THEMES)
Onsite assessment is still fundamental.
Onsite assessment should be a first step, before simulations.
An expert onsite will always be more accurate than a simulation.
Indoor/Outdoor requests simulations. Outdoor only not really.
If the 2 seasons scenarios are too far apart to wait for.
If the area is too complex, then simulations are necessary.
For unknown future scenarios is useful.
To quickly compare existing vs proposed.
If the area is not accessible, or too far.
The client usually sets the request. So the goal is determined by the client.
The goal (why is it studied?) should be known from the start.
It could be done for design, for assessment or for guidelines.
At the beginning is optimal but in all stages is possible. Later is more costly.
Architects
Specialized in GIS
Civil Engineers
Meteorologists
Urban Planners
Building Physics
In general, specialized people who usually do not come into play for the other phases of the projects. Not enough integration. More efficient.
Knowledge and Communication is needed.
Iterative process between planning office, architecture firm and consultancy.
At least one person knowing the project along its entire process.
When the approach is as planners, all variables must be tackled simultaneously.
Computer-time consumption during the simulation.
Human-time consumption during the selection/cleaning of adequate input data.
Scale vs area can be a limitation.
Greater variables when assessing an open environment.
Software limitations when the client wants quick answers.
Human interpretation is still an important factor after simulations.
Understand a simulation as an approximation to reality, not reality itself.
You need expertise, excepticism, interpretation skills.
A more holistic view on the ecosystems is still necessary, not only individual parameters.
Urban Heat Island
Energy Performance
Climate Adaptation
Human Thermal Comfort
Pollution / Health.
A simulation will not be as precise as reality, but this is not the intention.
Imprecision should be accepted and use the tendency, trend, perspective of the output.
Plug-ins are becoming more and more relevant.
3D visuals are useful for non-experts.
Usually results are destined for non-expert actors who need content translated or simplified.
How to simplify content without banalizing? Another human-interpretation step.
Communication is a human-step.
Communicating the result is also a teaching process of the content.
Communicating the result is within a chain of stakeholders which should not be broken, so content must be clear.
From results Consensus must be achieved for decision-making.
The client can be varied.
The client is non-expert in microclimate topic.
The client sets the request (goal).
The client makes the final decision.
The client sets the pace (time).
Broaden the scope, involve other ecosystems.
Simulate more future scenarios.
Involve Health Data.
More city measurements.
Faster software.
More studies on Impact of Green Facades.
Assess more indoor/outdoor.
<< MAIN CONCLUSIONS (OVERALL)
Optimize the exchange or complement between onsite and simulation assessment for microclimate
Prevent that simulations take over the indispensable task of onsite assessment.
Simulations (in comparison to site assessment) are an advantegeous tool for:
Indoor / Outdoor
Complex Areas
International Areas
Non-existing Areas
Extreme Seasons Dif.
Scenario Comparison
Define from the start with the client the Goal of the task, before considering if simulations are needed.
Determine if the task is requested for:
Design
Assessment
Guidelines
Adapt to which stage of the project the simulation is being requested:
Beginning / Concept Phase: Less is defined, so more can be determined, but too many variables are open. It is still the most ideal moment for many.
Intermediate / Development Phase: Possibility for iteration in the planning.
End/ Detail Phase: More is defined to model but less can be changed, still materials can be determined, the late decisions will cost more for the overall project.
Notions of urban planning are important, but also expertise in climate and physics is important. Data knowledge is becoming very relevant, it seems in the future will be indispensable to know.
More integration between the tool user and other areas of the development process must be reinforced.
Knowledge and Communication is of upmost importance.
Constant iterative process between planning office, architecture firm and consultancy.
At least one person knowing the project along its entire process and areas.
Software Improvements needed:
Less time-consumption, specially running the simulation model.
Simplify the complexity between large scale areas and detailed grid size.
Differentiate between a detailed and a simpler Model. Develop a simpler version for rough quick answers (in the case of clients with time constraints).
To counteract human hurdles:
Simplify the human task of gathering and cleaning input data.
Increase quality and availability of data from cities (standardize?).
Educate further on how to interpret results from simulations.
Share expertise and perspective among different disciplines involved in the use of simulation tools and also those involved in the communication process.
Usual Targets to assess microclimate with simulation tools:
Urban Heat Island
Human Thermal Comfort
Climate Adaptation
Energy Performance
Pollution / Health.
A more holistic view across different ecosystems is still necessary, beyond solely the human ecosystem. Therefore it is not recommended to focus on one single Target and its parameters.
Imprecision should be accepted when performing simulations and use the tendency, trend, perspective of the output. Acknowledge that it will not replicate reality.
Instead of considering one single appropriate software as the best simulation tool option, make more transparent the availability of free-access plug-in tools and their diverse advantages for each case.
3D visuals are useful means of representation for non-expert users.
Acknowledge that communicating results is an important and time-consuming human process of the assessment.
Assume that the communication process should be made with an educational approach when the recipient of the information is a non-expert.
The content should at all times be understandable for all types of actors involved, in order to guarantee a successful communication along the chain of stakeholders and to reach consensus on the decisions taken.
Request from the client from the beginning:
Field of applicability of the task requested.
The purpose of the study requested (design, assessment, guidelines).
Timeframe for delivery of solutions.
His/her background and level of understanding on the topic.
Where to point at in the coming years with microclimate simulations:
Look more into the realm of public health and synchronize with public health data.
Broaden the scope of assessment across multiple ecosystems, not only human the human environment.
Simulate more future scenarios, not only current scenarios.
Deepen into microclimate studies focused on indoor/outdoor symbiosis.
Deepen into the impact of the use of Green Facades and its contribution to evapotranspiration in urban contexts.
<< FROM CONCLUSIONS TO RECOMMENDATIONS



INTERVIEW ACTIVITY
(THEMATIC ANALYSIS)
CODES
SYNTHESIS
MAIN THEMES
SUB-THEMES OR CATEGORIES
MAIN CONCLUSIONS PER CATEGORY (SYNTHESIS)
FROM CONCLUSIONS TO RECOMMENDATIONS
6 experts interviewed
relevant data from interviews identified and summarized in sentences.
synthesis process of clustering identified codes into common themes.
interpretation process
problem to solution (opposite statement)
INTERNAL WORKFLOW
SIMULATION PROCESSES
DECISION-MAKING PHASE
THEMES CLUSTERED
APPLICATION
WORKFLOW
HURDLES
OUTPUT
REPRESEN TATION
COMMUN ICATION
THE CLIENT / END-USER
FUTURE DEVELOP MENT
ANALOG VS DIGITAL
WHEN IS IT INDISPENSABLE TO USE SIMULATIONS?
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BEST STAGE OF PROJECTS FOR MC ASSESSMENT?
WHO PERFORMS SIMULATIONS?
TEAM WORKFLOW FOR MICROCLIMATE
TIME RESOURCE/ COMPUTER POWER
SCALE / RANGE
INPUT DATA
EXPECTATIONS OF RESULTS
TARGET / WHAT IS ASSESSED?
PRECISION
TRANSLATION / DECODING / ADDITIONAL TOOLS?
clustered conclusions
clustered recommendations

ANNEX B – Field Measurements

ANNEX - B1

LOCATION 1: GRASBROOK PARK

Details (A)

LOCATION						BEFORE MEASUREMENTS (DWD)					ON-SITE MEASUREMENTS										
		Hamburg				Preparation					self-assessment					POINT 1 - HIGH		POINT 2 - LOW			
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm, Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Direct Sun Y/N	Surface Temperature (with IR)	Direct Sun Y/N	Surface Temperature (with IR)	Surface Temperature (w. Therm.)
FAÇADE	White Plaster (1) / Dark Brick (2)	Am Grasbrook Park	1	15 m. (point 1) and 11.5m. (point 2)	South	15.09.20	90	86	15,9	1,1	6:55	N	0,49	78,4	16,5	N	14,2	N	18,9	18,8
								87	15,4	1,4	9:05	F	0,89	66,3	20,1	Y	19,6	Y	27,5	24
								71	20,3	1,9	10:29	F	0,98	60,6	22,7	Y	22,3	Y	33,4	29,3
								64	22,4	1,7	11:34	F	1,4	53,3	25,9	Y	27,7	Y	43,9	39,6
								56	25,3	2,5	12:41	F	1,6	45,5	29,2	Y	30,5	Y	51,2	46,6
								49	27,4	2,8	13:50	F	1,1	43,4	30,2	Y	33,5	Y	53,2	49,7
								46	28,4	3,1	15:14	F	0,6	43,3	31,7	Y	34,4	Y	51,9	45,4
								47	28,9	1,4	16:17	F	0,7	42,9	32	Y	32,6	Y	52,2	47,2
								48	29,3	2,2	17:20	F	0,6	41,8	31,5	Y	29,2	Y	44,2	44,8
								47	28,2	3,1	18:22	F	0,4	44,1	29	N	26,9	N	40,2	39,7
								51	26,7	2,2	19:23	F	0,2	53,2	26,1	N	23,9	N	36,4	35,9
								75	21,6	0	20:29	N	0	56,9	25	N	22,5	N	34,1	32,6

WIND SPEED DIFFERENCE (app / onsite)	AIR TEMP DIFFERENCE (app/onsite)	HUMIDITY DIFFERENCE (app/onsite)	DIFF. BETWEEN THERMOMETER AND INFRARED
0,61	0,6	7,6	0,1
0,51	4,7	20,7	3,5
0,92	2,4	10,4	4,1
0,3	3,5	10,7	4,3
0,9	3,9	10,5	4,6
1,7	2,8	5,6	3,5
2,5	3,3	2,7	6,5
0,7	3,1	4,1	5
1,6	2,2	6,2	-0,6
2,7	0,8	2,9	0,5
2	-0,6	-2,2	0,5
0	3,4	18,1	1,5
1,20	2,51	8,11	2,79

Details (B)

LOCATION						BEFORE MEASUREMENTS (DWD)					ON-SITE MEASUREMENTS										
		Hamburg				Preparation					self-assessment					POINT 1 - HIGH		POINT 2 - LOW			
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm, Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Direct Sun Y/N	Surface Temperature (with IR)	Direct Sun Y/N	Surface Temperature (with IR)	Surface Temperature (w. Therm.)	DIFF. BETWEEN THERMOMETER AND INFRARED
FAÇADE	Dark Metal / Glass	Grisser Grasbrook	17	25	South	15.09.20	90	86	15,9	1,1	6:55	N	0,49	78,4	16,5	N	15,7	N	16,6	11,4	5,2
								87	15,4	1,4	9:05	F	0,89	66,3	20,1	Y	32	Y	25	23,2	1,8
								71	20,3	1,9	10:29	F	0,98	60,6	22,7	Y	41,7	Y	32,1	29,3	2,8
								64	22,4	1,7	11:34	F	1,4	53,3	25,9	Y	54,5	Y	39,2	34,1	5,1
								56	25,3	2,5	12:41	F	1,6	45,5	29,2	Y	59,6	Y	44,6	42,5	2,1
								49	27,4	2,8	13:50	F	1,1	43,4	30,2	Y	52,9	Y	45,7	46,1	-0,4
								46	28,4	3,1	15:14	F	0,6	43,3	31,7	Y	56,5	Y	46,7	46	0,7
								47	28,9	1,4	16:17	F	0,7	42,9	32	Y	46	Y	39,3	40,2	-0,9
								48	29,3	2,2	17:20	F	0,6	41,8	31,5	Y	38,9	Y	35,5	34,2	1,3
								47	28,2	3,1	18:22	F	0,4	44,1	29	N	30,8	N	30,7	31,7	-1
								51	26,7	2,2	19:23	F	0,2	53,2	26,1	N	26,8	N	27,7	27,2	0,5
								75	21,6	0	20:29	N	0	56,9	25	N	25,2	N	25,9	24,8	1,1
																					1,53

Details

LOCATION						BEFORE MEASUREMENTS (DWD)					ON-SITE MEASUREMENTS					
		Hamburg				Preparation					self-assessment					
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm, Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Surface Temp. (°C)
PAVEMENT	Asphalt (Light Grey)	Am Grasbrook Park				15.09.20	90	86	15,9	1,1	6:55	N	0,49	78,4	16,5	17,4
								87	15,4	1,4	9:05	F	0,89	66,3	20,1	20,4
								71	20,3	1,9	10:29	F	0,98	60,6	22,7	22,5
								64	22,4	1,7	11:34	F	1,4	53,3	25,9	28,3
								56	25,3	2,5	12:41	F	1,6	45,5	29,2	30,8
								49	27,4	2,8	13:50	F	1,1	43,4	30,2	34,3
								46	28,4	3,1	15:14	F	0,6	43,3	31,7	34,9
								47	28,9	1,4	16:17	F	0,7	42,9	32	33,7
								48	29,3	2,2	17:20	F	0,6	41,8	31,5	33,2
								47	28,2	3,1	18:22	F	0,4	44,1	29	32,5
								51	26,7	2,2	19:23	F	0,2	53,2	26,1	27,5
								75	21,6	0	20:29	N	0	56,9	25	25,5

ANNEX - B2

LOCATION 2: KAISERKAI (NORTH-SOUTH)

Details (C)

LOCATION						BEFORE MEASUREMENTS (DWD)					ON-SITE MEASUREMENTS									
Hamburg						Preparation					self-assessment					POINT 1 - HIGH		POINT 2 - LOW		
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm. Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Direct Sun Y/N	Surface Temperature (with IR)	Direct Sun Y/N	Surface Temperature (with IR)	Surface Temperature (w. Therm.)
FAÇADE	Dark Brick	Am Kaiserkai	11	21m. (point 1) and 18m. (point 2)	East	15.09.20	90	88	15,2	1,4	7:50	N	0,43	76	16,9	N	17	N	18,6	
								80	17,5	2,2	9:41	F	0,39	66,1	20	N	18,4	N	20,5	19,4
								71	20,3	1,9	10:55	F	1	61,3	22,6	Y (top)	19,7	N	20,3	21,6
								64	22,4	1,7	12:02	N	0,45	57,5	24,6	Y	26,2	Y	25,7	25,4
								56	25,3	2,5	13:09	N	2,1	48,2	28,2	N	25,4	N	27,4	26,8
								42	28,8	2,8	14:18	F	1,1	45,6	29,3	N	26,6	N	26,9	27,9
								46	28,4	3,1	15:40	F	1,1	48,1	29	N	29	N	28,6	29,2
								47	28,9	1,4	16:41	F	0,86	47,3	29,3	N	30,2	N	28,9	29,7
								48	29,3	2,2	17:43	F	1,2	47,1	28,1	N	29,7	N	29	28,9
								47	28,2	3,1	18:47	F	0,45	48,8	27	N	29,4	N	28,2	27,6
								51	26,7	2,2	19:47	N	0,1	54,4	25,5	N	25,4	N	26	25,8
								75	21,6	0	21:00	N	0,7	62,3	23,6	N	25,3	N	26,6	24,9

WIND SPEED DIFFERENCE (app / onsite)	AIR TEMP DIFFERENCE (app/onsite)	HUMIDITY DIFFERENCE (app/onsite)	DIFF. BETWEEN THERMOMETER AND INFRARED
0,97	1,7	12	
1,81	2,5	13,9	1,1
0,9	2,3	9,7	-1,3
1,25	2,2	6,5	0,3
0,4	2,9	7,8	0,6
1,7	0,5	-3,6	-1
2	0,6	-2,1	-0,6
0,54	0,4	-0,3	-0,8
1	-1,2	0,9	0,1
2,65	-1,2	-1,8	0,6
2,1	-1,2	-3,4	0,2
-0,7	2	12,7	1,7
1,22	0,96	4,36	0,08

Details (D)

LOCATION						BEFORE MEASUREMENTS (DWD)					ON-SITE MEASUREMENTS									
Hamburg						Preparation					self-assessment					POINT 1 - HIGH		POINT 2 - LOW		
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm. Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Direct Sun Y/N	Surface Temperature (with IR)	Direct Sun Y/N	Surface Temperature (with IR)	Surface Temperature (w. Therm.)
FAÇADE	White Plaster	Am Kaiserkai	5	22m. (point 1) and 18m. (point 2)	West	15.09.20	90	88	15,2	1,4	7:50	N	0,43	76	16,9	N	14,6	N		16,7
								80	17,5	2,2	9:41	F	0,39	66,1	20	N	19,2	N		19,5
								71	20,3	1,9	10:55	F	1	61,3	22,6	N	20,1	N	21,6	21,9
								64	22,4	1,7	12:02	N	0,45	57,5	24,6	N	22,7	N	24	24
								56	25,3	2,5	13:09	N	2,1	48,2	28,2	Y	25,8	N	26,1	26,7
								42	28,8	2,8	14:18	F	1,1	45,6	29,3	Y	34,3	Y	35,2	33,5
								46	28,4	3,1	15:40	F	1,1	48,1	29	Y	31,7	Y	30,5	30,2
								47	28,9	1,4	16:41	F	0,86	47,3	29,3	Y	38,3	N	28,2	29,1
								48	29,3	2,2	17:43	F	1,2	47,1	28,1	Y	35	N	29,7	28,3
								47	28,2	3,1	18:47	F	0,45	48,8	27	N	24,8	N	25,7	26,6
								51	26,7	2,2	19:47	N	0,1	54,4	25,5	N	21,8	N	23,3	24,1
								75	21,6	0	21:00	N	0,7	62,3	23,6	N	22	N	23,9	22,8

DIFF. BETWEEN THERMOMETER AND INFRARED
-0,3
0
-0,6
1,7
0,3
-0,9
1,4
-0,9
-0,8
1,1
0,10

Details

LOCATION						BEFORE MEASUREMENTS (DWD)					ON-SITE MEASUREMENTS					
Hamburg						Preparation					self-assessment					
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm. Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Surface Temp. (°C)
PAVEMENT	Basalt Brick Stone	Pocket street am Kaiserkai				15.09.20	90	88	15,2	1,4	7:50	N	0,43	76	16,9	17,5
								80	17,5	2,2	9:41	F	0,39	66,1	20	19,4
								71	20,3	1,9	10:55	F	1	61,3	22,6	21,2
								64	22,4	1,7	12:02	N	0,45	57,5	24,6	22,1
								56	25,3	2,5	13:09	N	2,1	48,2	28,2	27,4
								42	28,8	2,8	14:18	F	1,1	45,6	29,3	28,9
								46	28,4	3,1	15:40	F	1,1	48,1	29	28,4
								47	28,9	1,4	16:41	F	0,86	47,3	29,3	28,3
								48	29,3	2,2	17:43	F	1,2	47,1	28,1	27,6
								47	28,2	3,1	18:47	F	0,45	48,8	27	25,9
								51	26,7	2,2	19:47	N	0,1	54,4	25,5	23,7
								75	21,6	0	21:00	N	0,7	62,3	23,6	23,2

ANNEX - B3

LOCATION 3: KAISERKAI (EAST-WEST)

Details (E)

Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm. Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Point 1 - High: Direct Sun Y/N	Point 1 - High: Surface Temperature (with IR)	Point 2 - Low: Direct Sun Y/N	Point 2 - Low: Surface Temperature (with IR)	Point 2 - Low: Surface Temperature (w. Therm.)
		LOCATION: Hamburg				BEFORE MEASUREMENTS (DWD): Preparation					ON-SITE MEASUREMENTS: self-assessment									
FAÇADE	Dark Brick	Am Kaiserkai	13	15 m. (point 1) and 11.5m. (point 2)	North	15.09.20	90	87	15,4	1,4	8:28	F	0,21	73	18,1	N	16,3	N		19,5
								80	17,5	2,2	9:56	F	0,88	64,2	20,9	N	18,1	N	21,2	20,5
								71	20,3	1,9	11:09	F	0,7	61	22,7	N	19,2	N	22	20,5
								56	25,3	2,5	12:18	N	0,79	56,8	25	N	21,3	N	22,9	23,4
								49	27,4	2,8	13:25	N	0,26	50,1	27,4	N	24,1	N	25	25,1
								42	28,8	2,8	14:32	F	0,2	47,3	28,9	N	25,6	N	25	26,6
								46	28,4	3,1	15:54	F	0,4	46,1	30	N	27,4	N	26,9	27,8
								47	28,9	1,4	16:59	F	0,9	48,4	28,6	N	26,2	N	27,1	28
								48	29,3	2,2	17:59	F	1,3	44,8	28	N	24,7	N	26,6	27,5
								47	28,2	3,1	19:01	F	0,4	49,7	26,7	N	23,5	N	25,9	26,8
								51	26,7	2,2	20:03	N	0	56,3	24,9	N	20,5	N	25,3	25,2
								87	19	1,4	21:19	N	0	61,4	23,6	N	21,3	N	26,3	24

WIND SPEED DIFFERENCE (app / onsite)	AIR TEMP DIFFERENCE (app/onsite)	HUMIDITY DIFFERENCE (app/onsite)	DIFF. BETWEEN THERMOMETER AND INFRARED
1,19	2,7	14	
1,32	3,4	15,8	0,7
1,2	2,4	10	1,5
1,71	-0,3	-0,8	-0,5
2,54	0	-1,1	-0,1
2,6	0,1	-5,3	-1,6
2,7	1,6	-0,1	-0,9
0,5	-0,3	-1,4	-0,9
0,9	-1,3	3,2	-0,9
2,7	-1,5	-2,7	-0,9
2,2	-1,8	-5,3	0,1
1,4	4,6	25,6	2,3
1,75	0,80	4,33	-0,11

Details (F)

Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm. Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Point 1 - High: Direct Sun Y/N	Point 1 - High: Surface Temperature (with IR)	Point 2 - Low: Direct Sun Y/N	Point 2 - Low: Surface Temperature (with IR)	Point 2 - Low: Surface Temperature (w. Therm.)
		LOCATION: Hamburg				BEFORE MEASUREMENTS (DWD): Preparation					ON-SITE MEASUREMENTS: self-assessment									
FAÇADE	White Plaster / Glass	Am Kaiserkai	10	25	South	15.09.20	90	87	15,4	1,4	8:28	F	0,21	73	18,1	Y	19,6	N		19,4
								80	17,5	2,2	9:56	F	0,88	64,2	20,9	Y	22,7	N	21	19,9
								71	20,3	1,9	11:09	F	0,7	61	22,7	Y (top)	26,3	N	20,3	21,4
								56	25,3	2,5	12:18	N	0,79	56,8	25	Y	31,2	N	21,6	22,3
								49	27,4	2,8	13:25	N	0,26	50,1	27,4	Y	35,3	Y	26	25,9
								42	28,8	2,8	14:32	F	0,2	47,3	28,9	Y	37,9	N	25,3	26,7
								46	28,4	3,1	15:54	F	0,4	46,1	30	Y	38,4	N	26,5	27,8
								47	28,9	1,4	16:59	F	0,9	48,4	28,6	Y	37,6	Y	28	28,4
								48	29,3	2,2	17:59	F	1,3	44,8	28	Y	35,6	Y	27,9	28,5
								47	28,2	3,1	19:01	F	0,4	49,7	26,7	N	33,3	N	27,5	27,5
								51	26,7	2,2	20:03	N	0	56,3	24,9	N	31,4	N	27,6	26,6
								87	19	1,4	21:19	N	0	61,4	23,6	N	30,5	N	27,1	25,3

DIFF. BETWEEN THERMOMETER AND INFRARED
1,1
-1,1
-0,7
0,1
-1,4
-1,3
-0,4
-0,6
0
1
1,8
-0,14

Details

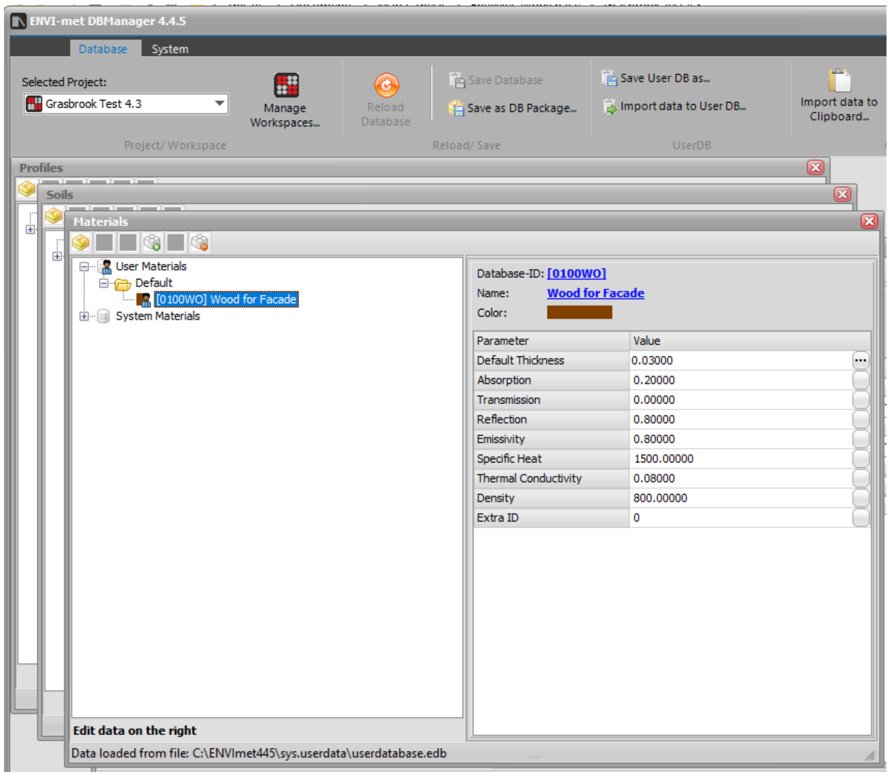
Type	Material	Street	Building No.	Distance (m)	Orientation	Date	Emissivity (%)	Rel. Humid. (%)	Atm. Temp °C	Wind Speed @ 16m. (m/s)	HOUR	Cloud Coverage (YES / FEW / NO)	Wind Speed (m/s) at 2m.	Rel. Humid. (%) at 1.5m.	Air Temp. (°C) at 1.5m.	Surface Temp. (°C)
		LOCATION: Hamburg				BEFORE MEASUREMENTS (DWD): Preparation					ON-SITE MEASUREMENTS: self-assessment					
PAVEMENT	Concrete Pavement (Medium Grey)	Am Kaiserkai				15.09.20	90	87	15,4	1,4	8:28	F	0,21	73	18,1	18,7
								80	17,5	2,2	9:56	F	0,88	64,2	20,9	19,5
								71	20,3	1,9	11:09	F	0,7	61	22,7	21,5
								56	25,3	2,5	12:18	N	0,79	56,8	25	23,7
								49	27,4	2,8	13:25	N	0,26	50,1	27,4	24,2
								42	28,8	2,8	14:32	F	0,2	47,3	28,9	25,7
								46	28,4	3,1	15:54	F	0,4	46,1	30	26,2
								47	28,9	1,4	16:59	F	0,9	48,4	28,6	26,2
								48	29,3	2,2	17:59	F	1,3	44,8	28	25,9
								47	28,2	3,1	19:01	F	0,4	49,7	26,7	24,9
								51	26,7	2,2	20:03	N	0	56,3	24,9	23,2
								87	19	1,4	21:19	N	0	61,4	23,6	22,6

ANNEX C – Material for Envi-Met User Database

C1 - Parameters for the creation of Wood as Façade material.

ANNEX - C1

ADDING A NEW MATERIAL TO THE USER DATABASE FOR THE ENVI-MET MODEL:



(screenshot taken from Envi-Met program)

CRITERIA TO DEFINE WOOD PROPERTIES AS FAÇADE MATERIAL:

- **Thickness: 3cm** plank with the main properties (source: *Der Woodcube—DeepGreen Development*. (n.d.). Retrieved June 18, 2021, from https://www.deepgreen-development.com/woodcube-hamburg)
- **Absorption: 0.2**, because absorption, transmission and reflection must add 1. It was the only missing value, after locating transmission and reflection (source: Envi-Met Company (2019). *ENVI_MET Unfolded Part 2: Building and Materials*. https://www.youtube.com/watch?v=bYDizdNrTo8).
- **Transmission: 0.00**, because it is not a translucent material (source: Envi-Met Company (2019). *ENVI_MET Unfolded Part 2: Building and Materials*. https://www.youtube.com/watch?v=bYDizdNrTo8).
- **Reflection: 0.80**. It is albedo according to answers in the Envimet forum, and albedo value was copied from Envimet Wood planks properties in the System Database.
- **Emissivity: 0.80** (from https://www.hindawi.com/journals/je/2019/4925056/)
- **Thermal conductivity: 0.08** (source: *Der Woodcube—DeepGreen Development*. (n.d.). Retrieved June 18, 2021, from https://www.deepgreen-development.com/woodcube-hamburg)
- **Density: 800** (source: Queensland Government. (n.d.). *QTimber. Wood density and hardness*. https://qtimber.daf.qld.gov.au/guides/wood-density-and-hardness).