Urban Design
MSc04-URB9

Master Thesis

Re: Hydrate

Integrating Sponge City principles through early design stage microclimate simulations to optimize for climate resilient and pedestrian friendly urban spaces – A design exploration of Gängeviertel in Hamburg, Germany

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SIGNATURES

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Reading Guide

This thesis is divided into ten chapters: Prologue, Research Framework, Context, Case Study, Theoretical Background, Site and Context, Spatial Analysis, Methods, Results, Design Proposal, and Epilogue. The Design Proposal will be discussed at the very end, as it represents the synthesis of the collected knowledge from the theory and analysis, as well as the result of microclimate simulations and rainwater-management optimization. Its complexity and interconnectedness make it necessary to be discussed prior.

Throughout the report, the Harvard Citation style is used to reference sources, and an overview of all sources can be found in the references at the end of the report. Likewise, all illustrations are referenced in a list at the end.

Ill. Wall Painting at Gängeviertel
Source: Own Image

Abstract

This project aims to optimize the usage of Sponge City principles and thermal comfort early into the design process, to efficiently transform urban spaces into climate-resilient and user-friendly places. Microclimate simulation and multi-objective optimization for rainwater-management systems are adopted to support the process of decision-making through performance-based standards.

Using the dynamic site between the Gängeviertel and Brahmsquartier, this project highlights the complexity of supporting the cultural dynamics of a site, while offering solutions to integrate green infrastructure, water retention systems, and nature-based solutions in a dense urban space. Through a data-driven and iterative process that is based on the Integrated Design Process, this thesis provides a design suggestion that demonstrates how small-scale interventions can contribute meaningfully to city-wide climate resilience goals. Finally, it outlines a transferable framework, the „Sponge City Toolbox“, for application in other dense urban contexts, ultimately acting as a pilot project for the climate-sensitive cities of the future.

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PREFACE

This thesis is submitted as part of the master's degree in urban design at the Department of Architecture, Design, and Media Technology at Aalborg University. The 30 ECTS research and design project marks the end of this semester program.

The work aims to investigate how Sponge City principles and microclimate simulations can be integrated into the design process and meaningfully change the climate resilience and quality of the pedestrian environment of a small urban space like the site between the Gängeviertel and the Brahmsquartier. Apart from a design proposal, this project additionally aims to provide a toolbox that can serve as an initial guide to other projects that seek to adopt Sponge City principles and improve thermal comfort.

Under supervision of Lea Holst Laursen, this thesis greatly increased in quality, and we are sincerely grateful for her guidance.

We would also like to extend our thanks to Martin from the Baukommission at Gängeviertel, whose insights were invaluable and added not only great realism to this thesis, but also reminded us of the importance of local expertise and lived experience, especially in the historically layered urban context.

Thank you.

MOTIVATION

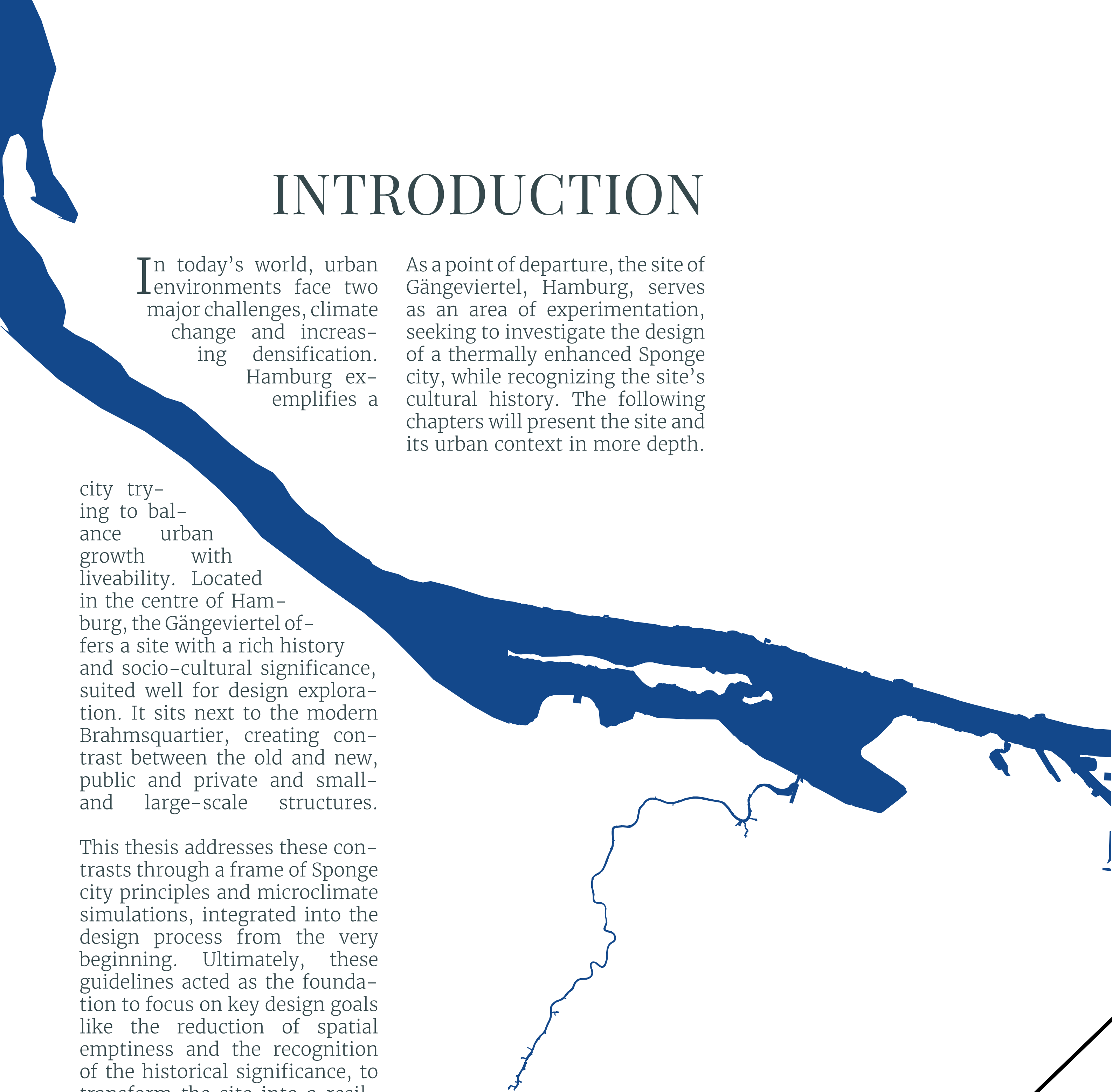
The cities of today face increasing climate challenges such as flooding and extreme heat, causing discomfort or even danger for urban residents. Cities like Hamburg aim to tackle these challenges by adopting **Sponge City principles**, subsequently seeking to redesign their urban fabric to accommodate the changing needs of life in today's urban environment. However, these initial steps are often inefficient and highlight the need for implementing Sponge City principles. Yet, in increasingly dense urban areas, available space is limited, and strategies for activating these **small, compact spaces** remain largely unexplored.

Making the most out of these small spaces, this project seeks to optimize for better **microclimatic conditions**, while utilizing the Sponge City principles given as the desired standard by many cities. Though complex in nature, assuming an understanding of the interplay between local climate, materials and hydrology, the traditional design process heavily relies on the architect's personal experience during the early design stages. Nevertheless, measurable benchmarks are often desired for a project to be advertised well yet, these factors are commonly considered in later stages, compromising the usability of the initial design concept.

This thesis therefore aims to **rethink** the traditional planning processes by integrating **microclimate simulations** early in the design process and using the information gathered to guide the design in an **iterative** process. By evaluating thermal comfort levels in relation to spatial possibilities for Sponge city principles, the design can not only be understood as aesthetically pleasing but also be optimized to effectively resolve climate related issues in a specific dense, urban context.

The result of this study showcases a **performance-driven methodology** that leads to climate resilient design, ensuring that cities develop in a **sustainable manner**.

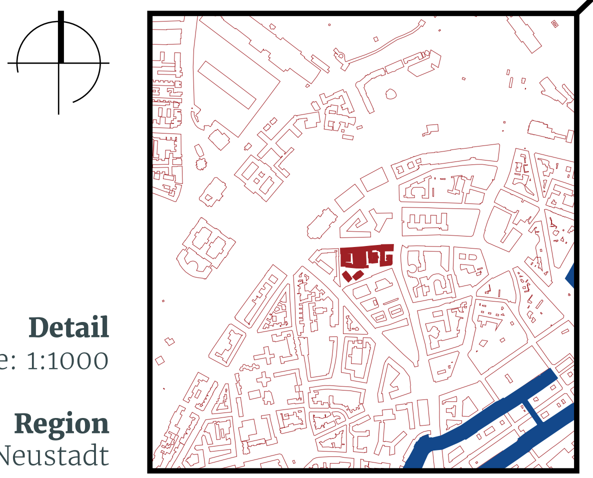
INTRODUCTION



In today's world, urban environments face two major challenges, climate change and increasing densification. Hamburg exemplifies a city trying to balance urban growth with liveability. Located in the centre of Hamburg, the Gängeviertel offers a site with a rich history and socio-cultural significance, suited well for design exploration. It sits next to the modern Brahmsquartier, creating contrast between the old and new, public and private and small- and large-scale structures.

This thesis addresses these contrasts through a frame of Sponge city principles and microclimate simulations, integrated into the design process from the very beginning. Ultimately, these guidelines acted as the foundation to focus on key design goals like the reduction of spatial emptiness and the recognition of the historical significance, to transform the site into a resilient and pedestrian friendly urban space. This project therefore not only aims to suggest a design solution for the given site but also offer a prototype for other sites thought Hamburg that can be retrofitted sustainably.

As a point of departure, the site of Gängeviertel, Hamburg, serves as an area of experimentation, seeking to investigate the design of a thermally enhanced Sponge city, while recognizing the site's cultural history. The following chapters will present the site and its urban context in more depth.



Detail
Scale: 1:1000

Region
Hamburg-Neustadt

Location
Scale: 1:10000

Region
North Germany

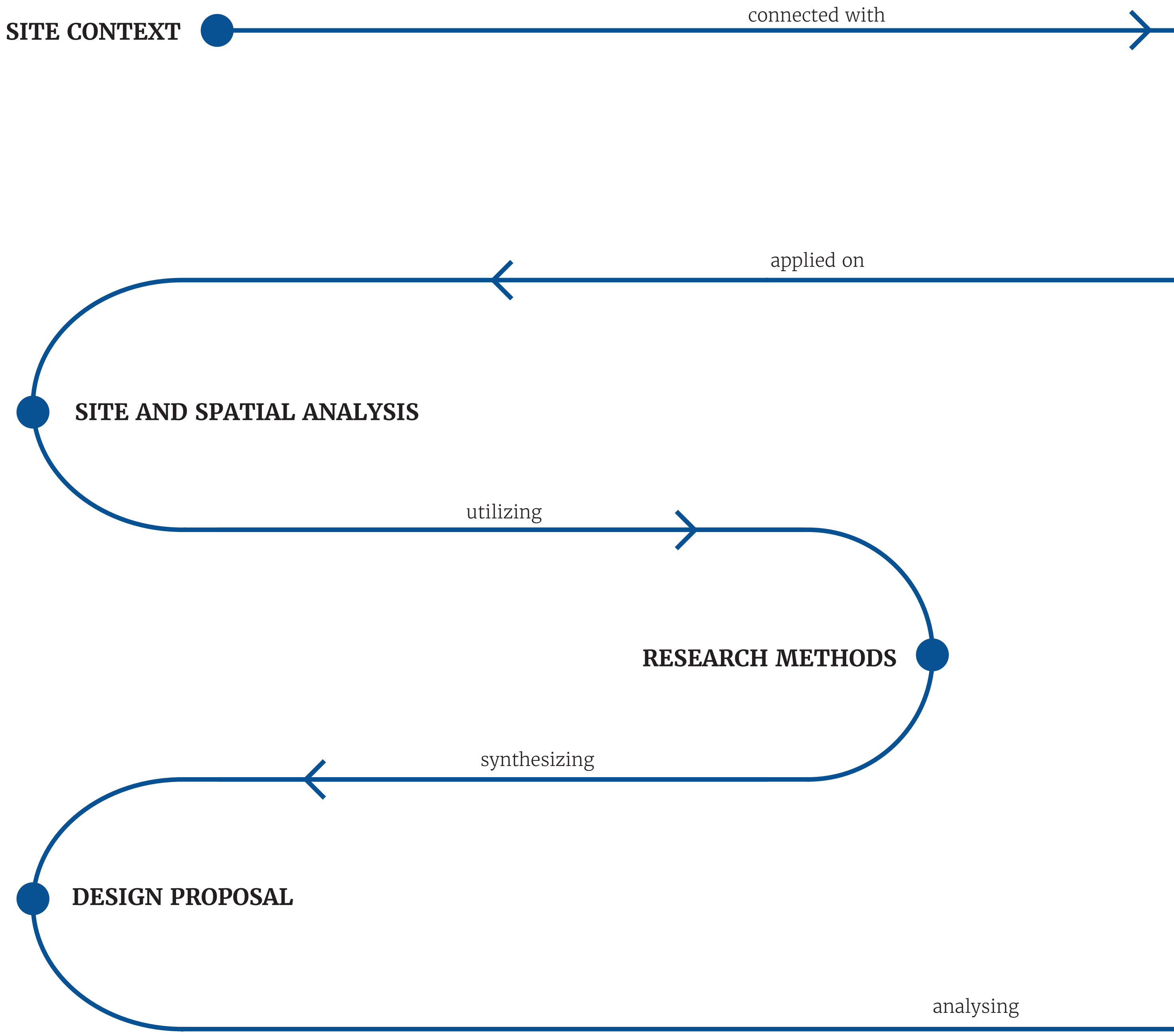
Ill. 1. Hamburg-Neustadt and its location in Hamburg
Source: Own Image
Dataset:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Water Areas- Freie und Hansestadt Hamburg, Behörde für Umwelt und Energie (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)

HAMBURG

Hamburg, a city shaped by its lakes, rivers, streams and canals, blends rich history with contemporary architecture in northern Germany (Freie und Hansestadt Hamburg, 2014). The bustling openness from the historic Speicherstadt to the vibrant Sternschanze showcases the slogan of the city "The gateway to the World", emphasizing its diversity, cultural exchange and economic vitality (Hamburg Tourismus GmbH, 2025).

Between Alster and Elbe, nestled in the centre of Hamburg, is the city district Hamburg-Neustadt. Known for areas like the "Jungfernstieg, the Elbpromenade or the Gängeviertel", this district is one of the biggest attractions in Hamburg and monument of past times (Freie und Hansestadt Hamburg, 2025).

RESEARCH FRAMEWORK



Ill. 2. Simplified project process
Source: Own Image

RESEARCH QUESTION

*„How can **site-specific Sponge City principles**, coupled with **microclimate simulations**, optimize climate resilience and pedestrian comfort in **compact urban spaces**?"*

THEORETICAL BACKGROUND

OVERVIEW, APPROACH AND STRUCTURE

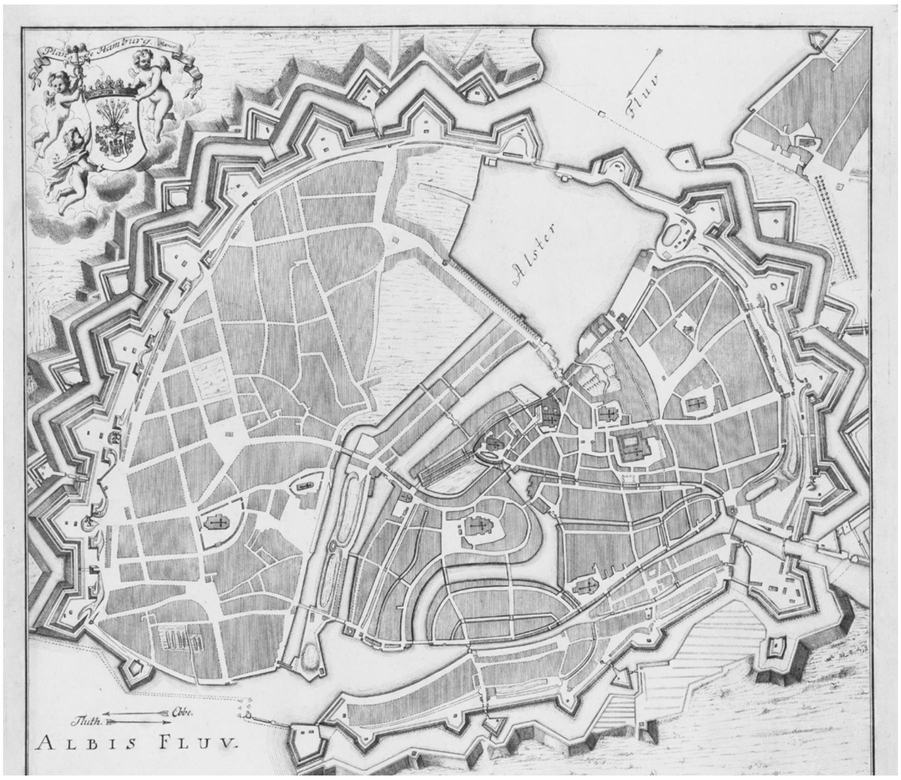
To answer this research question, the structure of this report departs with a general introduction to the topic, followed by a contextual analysis including site specific climate, geometry and spatial relationships. Subsequently, to set a foundation, the following theoretical chapter introduces the key concepts of Sponge cities, Urban heat islands and performance-based design. After highlighting the research methods that include simulation tools to assess thermal comfort and a spatial optimization for Sponge city principles, the design proposal will be introduced through a synthesis of the main learnings, derived from the analysis, theory and methods. The design proposal applies these insights to the local context and suggests interventions that increase comfort, manage rainwater and support cultural exchange. Finally, the knowledge gained is summarized in the "Sponge city toolbox" and issues in the application of the design process discussed.

EVALUATION

CONTEXT

THE HISTORY OF HAMBURG

The founding of the city of Hamburg dates back to a village from the 9th Century. Back then, this village was known under the name "Hammaburg", combining the two words: "Ham/Hamme" (transl. swampy terrain) and "Burg" (fortified area protected by wall (Freie und Hansestadt Hamburg, 2025). After the city got destroyed in the following years and rebuilt, it received in 1266 the privileges from the Roman German Emperor Friedrich Barbarossa to be a Trade city. This is recognized as the "Birth" of Hamburg's harbour and the Hamburg's rise to becoming a powerful city in Germany. Originally, this harbour was located at the river "Bille" (now "Alster") and was later moved to the Elbe to due to ships becoming larger. Nonetheless, the Region around the Alster remained the political and economic heart of the city until the 19th century. After the old harbour had burned down in 1842, it was decided to build the "Speicherstadt" in 1871, causing the destruction of numerous residential houses. Nevertheless, Hamburg kept growing outwards, becoming more and more dense and leading to the creation of "Gängeviertel". These districts are characterized through narrow labyrinth like pathways and will be detailed in the section History and development of the Gängeviertel, p.14 (Freie und Hansestadt Hamburg, 2025).



Ill. 3. Historical map of Hamburg 1722 (Mezner, ..., Fritsch, Christian)
Source: Staats- und Universitätsbibliothek Hamburg (https://resolver.sub.uni-hamburg.de/kitodo/PPN611980622)

Ultimately, Hamburg's economic rise during the last centuries and, in consequence, the dense urban development around different harbor areas, is part of the reason for today's urban challenges. Alongside the development plans of Hamburg, that will be detailed in the next chapter, microclimate simulations and sponge city principles can aid in creating an urban environment that balances economic progress with environmental resilience.

DEVELOPMENT VISION OF HAMBURG

With its population nearing two million and continued economic expansion, Hamburg focuses on balancing urban growth with social and environmental considerations. The vision of the city revolves around sustainable growth, urban densification, climate resilience and enhanced mobility. One of the guiding principles is "Mehr Stadt in der Stadt" (transl. to More city in the city), focusing on further urban densification, while considering the management of blue and green infrastructures. As part of Hamburg's development plan, preserving open spaces with high quality and multifunctionality has become a key factor. A few of the recent projects in Hamburg, such as the infamous HafenCity, but also less internationally known areas like Grasbrook or Oberbillwerder, showcase how urban densification can be balanced recreational characteristics, by introducing areas for mixed-uses (BSW, 2019a).

Considering Hamburg's history of floodings and the general importance of water management in today's urban areas, Hamburg has adopted certain sponge city principles as a way of enhancing urban resilience (BSW, 2019a). Details on this follow in the Theoretical Background section, p.20 ff..

With focus on urban development till 2040(+), Hamburg put forward a specific plan to develop its major lanes of transport (Magistralen). Recognizing the importance of urban mobility, Hamburg plans to redefine major transport axes which are traditionally dominated by car traffic. These corridors are supposed to be rethought as multi-functional spaces that put alternative modes of mobility in the foreground, such as walking, biking or public transport. This transformation goes along with the creating of green corridors that improve air quality and urban aesthetics (BWS, 2019b). Another cornerstone of Hamburg's development vision is ensuring social inclusion and affordability. Initiatives like affordable housing policies, mixed use neighbourhoods and refugee housing integration ensure accessibility for low-income residents and foster diversity and social interaction (BSW, 2019b).

Concludingly, Hamburg's development vision is diverse and follows principles of sustainability, resilience and inclusivity. The goal is to simultaneously achieve strategic urban densification and maintain a high quality of urban spaces that are socially accessible, even for low-income residents. Creating mixed-use areas is the focal point of Hamburg's endeavours to promote resilience and social exchange.

Ill. 4. Raised terrain to support the growth of trees, Hafencity Hamburg
Source: Own Image

Ill. 5. Water-playground, Hafencity Hamburg
Source: Own Image

CASESTUDY

HISTORY AND DEVELOPMENT OF THE "GÄNGEVIERTEL"

„Labyrinth of houses, huts, dirt, and misery"
-Asher, H. 1865: 5

The Gängeviertel originated in the 12th century and stretched out over almost the entirety of what is today known as the Old and New Town. As of today, barely any remnants of the Gängeviertel are visible (Dahms, 2010).Attracted by the harbour as the main employer at the time, many people moved into this area and built their small half-timbered houses. Space was limited and, as most buildings were not directly placed along the designated streets, they could only be reached through narrow pathways. These narrow pathways are what gave these districts their characteristic name (Joeres, 2010; Grüttner, 1983).Later, in the 18th century, Hamburg became a centre of trade in Northern Europe, resulting in a stark population growth and, eventually, a lack of housing (Evans 1996).New houses could not be constructed outside of the city because of a legal entrance blockage, prohibiting people from entering or exiting at night (Evans, 1996; Dahms, 2010)By the beginning of the industrialization in the 19th century, houses had to be expanded with additional levels, and room sizes were reduced. Not only were these houses small but also extremely unhygienic. Regular flooding and, at that time, an open canal, turned the Gängeviertel into a breeding ground for diseases (Grüttner, 1983; Evans, 1996). The Gängeviertel was also known as the "Labyrinth of houses, huts, dirt, and misery" Asher, H. 1865: p. 5. In response to the miserable conditions, the city of Hamburg decided to tear the buildings down and rebuilt the district from the ground with a new focus on the creation of large office and commercial buildings with wide, continuous streets (Asher, H., 1865).

In 2009, the last remains of the historical district, intended to be sold to private investors and finally demolished, caused several local initiatives to protest and occupy 12 different buildings (Füllner and Templin, 2011). To fight for a more democratic and just city with the slogan "Right to the city", these initiatives advertised against gentrification and privatization (Füllner and Templin, 2011, p.7). The city of Hamburg ultimately gave in, and the attention of this intervention started conversations about transforming Gängeviertel into the vibrant socio-cultural centre that it is today (Gängeviertel Genossenschaft 2010 eG, 2014). Finally, the Gängeviertel was recognized by the UNESCO and became an example for cultural diversity (Gängeviertel e.V., 2015a).

Ill. 6. The house at Speckstraße 60, Hamburg, 1925 (J. Hamann)
Source: By Wikimedia Commons (https://commons.wikimedia.org/wiki/File:G%C3%A4ngeviertel-Brahms-Geburtshaus_1925.jpg)

Being one of the areas in Hamburg with the richest history, its development over the century's, diminishing from a social and economic centre to an overcrowded place full of poor living conditions, to then later be transformed into a commercial district, acts as a reminder of the challenges posed by rapid urbanization and the evolving priorities of city planning.

Ill. 7. View into today's Gängeviertel
Source: Own Image

GÄNGEVIERTEL PROJECT AND TODAYS USAGE

Motivated by working against profit-driven urban developments that neglect the needs of the community, the Gängeviertel project fights gentrification and the institutionalization of artists for gentrification purposes. The vision of the project is to foster a cultural and social hub that gives room for art, culture and community activities, accessible by all. The project also aims to create a platform for urban experimentation, where people from all cultural backgrounds are invited to explore forms of communal living, self-governance and sustainable urban practices (Gängeviertel e.V., 2015b)

Four key principles are recognized by the Gängeviertel e.V. (2015):

- Openness and accessibility
- Self determination
- Cultural diversity
- Affordable living and working space

Planning-wise, the total 12 buildings and 3 streets are organized into different types of spaces, ranging from residential spaces, artistic and creative spaces to socio-cultural spaces and commercial spaces. About 5.250m² of living space are distributed in the whole area, hosting about 125 people (Gängeviertel e.V. 2015b). A more detailed analysis of the building functions will be conducted in the Chapter Site and Context analysis, p.42.

The project further establishes goals for the intended structure of the historical buildings and the open space between them. The historic buildings should maintain their unique character and only be modernized to improve energy efficiency and sustainability through new insulation or new renewable energy sources and water saving systems. The open spaces in between are up for programming, though the open area along the Speckstraße is supposed to provide a contrast to the dense urban environment by incorporating a new park area. The Schier's Passage on the other hand is thought to be preserved as a pedestrian friendly route through the district (Gängeviertel e.V. 2015b).

„Wir sind die Stadt, denn: Die Stadt sind wir alle"

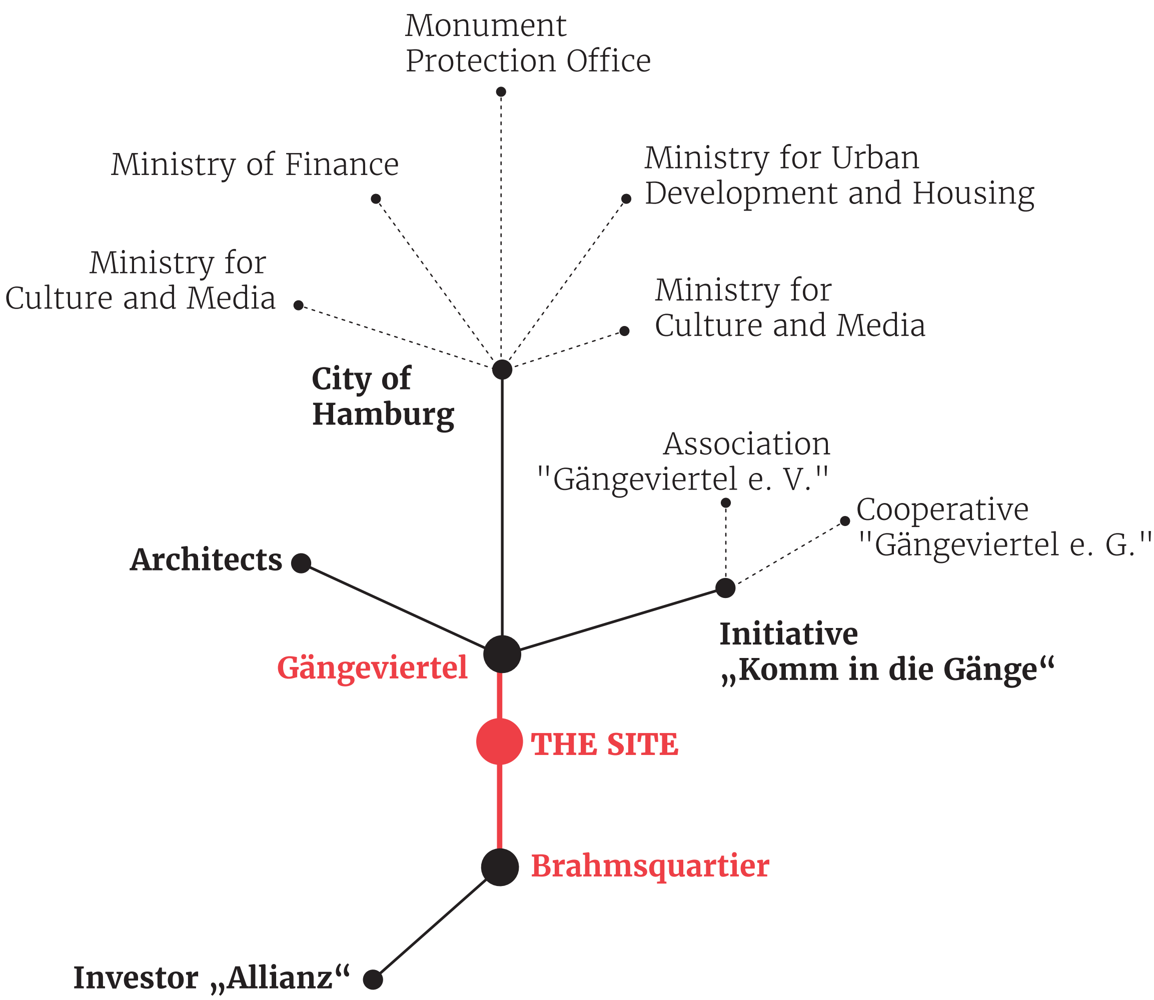
-Gängeviertel e.V., 2015c

Ill. 8. East side entrance and entrance to the underground parking at Brahmsquartier
Source: Own Image

BRAHMSQUARTIER

Adjacent to the historical Gängeviertel is the Brahmsquartier (see Ill. 8). Constructed in 2009, the mixed-use office and residential building stretches over the entirety of the southern boundary of the site (Hamburg Invest, 2025). Framed by the historical Gängeviertel in the north and the office building in the south, are two residential buildings with 8 floors. These feature shops and a restaurant on the Groundfloor.

Both, the buildings and the outdoor space in the Brahmsquartier, have been designed by Carsten Roth Architects (Carsten Roth Architekt., n.d.). Due to the newly built character of the Brahmsquartier, it stands in contrast with the Gängeviertel, not only in terms of design language, but also its usage and social clientele. This will be discussed in the following chapter.



Ill. 9. Stakeholder involvement at Gängeviertel and Brahmsquartier
Source: Own Image based on R-ein.de (n.d); Brahmsquartier.com (n.d.)

VISION FOR THE SITE

To design a project that creates real impact, it's important to know what its users think of the place and what their visions are for it. Due to the split nature of the site, composing of the Gängeviertel in the North, and a private street and Office, Housing space to the south, multiple actors are at play that need to be understood to make a good design (see Ill. 9).

While the Gängeviertel on paper aims to be a community lead district, the reality involves several actors that at times follow different agendas, with different visions on the Gängeviertel's future (Gängeviertel e.V. 2015b). On one side, the Gängeviertel Association works together with volunteers, trying to find "do-it-yourself" solutions for the complex historical site. On the other side, collaborators such as the city of Hamburg further complicate the situation, requiring compliance with regulations on issues like general safety, fire safety, building integrity, and other technicalities, which, due to a variety of reasons, one of them being lack of money, the Gängeviertel Association struggles to adhere to (Gängeviertel Genossenschaft 2010 eG (2014); see appendix A). Because of these ongoing debates, and the Gängeviertel Association's continuous efforts to push legal boundaries, often requiring unique, case-by-case solutions, the restauration of the buildings that was meant to be done in the next few years will more likely stretch out for at least 15 more years, says "Martin", one of the Landscape Architects that is both part of the planning and construction on the site (appendix A).

Martin further elaborates that the focus of the outdoor spaces in the Gängeviertel is multifunctional, movable, and affordable interventions that are localized with as much impact as possible (appendix A).

Ill. 10. Art installation of headless statue at Gängeviertel
Source: Own Image

THEORETICAL BACKGROUND

SPONGE CITY CONCEPT

The following chapter introduces the theoretical foundation that will later be used to address the identified urban challenges. It focuses on the sponge city concept, the importance and design of thermally comfortable urban space and the role of performance-based design as part of a holistic design process in resilient urban transformations.

While heavy rainfalls are predicted to increase in the future, cities are growing denser with higher rates of impermeable pavements. Traditional methods of water management are reaching their limits when facing stricter weather (Shastri et al., 2019; Qiao et al., 2020). These traditional practices include a centralized, rapid water removal and are criticized for being less effective than nature-based solutions (Qiao et al., 2020; Gao et al., 2016). In the pursuit of finding solutions to water management in today's city's, the sponge city concept represents a significant shift away from central drainage systems and stormwater management to local retention and use of rainwater in urban development (Jiang et al., 2017). Originating from China in 2013-2014, the term "Sponge city" draws inspiration from "the ability of natural sponges to absorb, store and slowly release large quantities of water "(Bau München, 2023). Utilizing the ideas posed in the sponge city concepts, the project site can be transformed into a resilient urban space that can adjust to changing conditions and provide an exemplary approach to linking water management with improvements to liveability (Wang et al., 2024).

This is not the first-time though, that concepts similar to Sponge cities have been theorized. Concepts like sustainable urban drainage systems (SUDs), to address water pollution and responding to water hazards, have been created in the United Kingdom (Chan et al., 2018; Griffiths, 2017).

Furthermore, in the 1990s, the term "low impact development" (LID) was recognized. LID promotes low impact techniques to manage stormwater close to its source to minimize the negative impact of urbanization on the natural water cycle (Whole Building Design Guide WBDG; Chan et al., 2018)

What makes the sponge city concept unique is its holistic approach to water management that focuses on the city holistically, combining water management, climate adaptation and urban liveability, making it the most compelling concept for this project (Chan et al., 2018).

It is this holistic approach that makes it attractive for big, fast-urbanizing cities like Chi-

RESILIENCE *[rɪˈzɪl.jəns]*

Urban resilience refers to the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales-to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.

- Meerow et al., 2016: 39

na or Hamburg, where the implementation of localized solutions is often not enough, and unattended climate-related water hazards risk resulting in severe consequences.

The Sponge city concept is based on 4 core principles (Nguyen et al., 2019):

- **Rainwater Absorption & Storage**
  Enhancing city surfaces to absorb and store rainwater, reducing stormwater runoff and flood risks

- **Water Ecology Management**
  Implementing self-purifying water systems and ecofriendly waterfront designs

- **Green Infrastructure**
  Using green infrastructure to purify, restore and reuse stormwater, mitigating pollution and the urban heat island effect.

- **Permeable Pavements**
  Incorporating permeable pavements in urban roads to improve water absorption

Nguyen et al. (2019) further distinguishes the micro and macro scale of sponge city principles. The macro level focuses on city wide or even regional strategies, integrating Sponge city principles into urban planning, infrastructure, and governance. On the micro level, small-scale interventions, similar to the aforementioned LIDs, aim at improving water absorption, storage, and purification at the building, street, or neighbourhood scale (Chan et al., 2018). While both macro and micro are important to ensure an effective and efficient implementation of sponge city principles, this project will consider macro level aspects theoretically but set its focus on the micro level (LIDs). The aim is to reduce urban runoff at the source, while improving water retention and ecological benefits for the area of the project site.

While the theory of sponge cities is extremely promising, it doesn't come without its difficulties and barriers. Nguyen et al. (2019) and Li et al. (2017) both outline 4 core barriers that currently slow down progress and big scale implementation of sponge city principles:

- **Technical and physical challenges**
  Due to its relative newness, field tested methods and extensive data on the effectiveness of new water management tools are scarce, especially when it comes to long term studies. Further applying sponge city principles to different countries and locations becomes not only difficult because trained personnel is generally rare, but also because of a lack of data on the site itself. Applying a generic solution without additional context disregards local differences in climate other factors.

- **Financial challenges**
  Due to the lack of predictability of long-term maintenance, it's hard to create a cost benefit analysis which makes it less attractive for investors to invest. Further, big scale constructions will be necessary to upgrade existing infrastructure, making its large adaptation difficult.

- **Legal and Regulatory Challanges**
  Currently, existing regulations and policies often prohibit the implementation of the sponge city concept. A lack of designated institutions and fragmented responsibilities to manage maintenance create weak enforcement measures.

- **Public's awareness and acceptance**
  Although public awareness about climate change related issues is rising, the public is still lacking knowledge on the importance and significance of the sponge city concept, reducing its general acceptance. This gets further intensified through insufficient coordination among different government agencies and poor data-sharing mechanisms that hinder research and innovation

Even when these nature-based solutions are well maintained and implemented, they can only be built for a certain level of extreme rain event. For China, the standard for newly built infrastructure is withstanding a 1:30 year rain-event, beyond that, an extreme event might still cause severe destruction (Chan et al., 2018). However, standards for Germany only suggest designing for a 5-to-10-year rain-event (DWA, 2005; DWA, 2013).

To summarize, Sponge city principles are a promising solution to combat the illnesses of ever denser cities suffering from climate change and outdated water management methods. The sponge city concept offers a holistic solution by integrating rainwater absorption, green infrastructure, and ecological restoration to enhance urban resilience. That said, challenges like technical execution, financial questions, legal difficulties and public awareness hinder widespread adaptation. Recognizing these obstacles, implementing sponge city principles on the neighbourhood scale can reduce challenges from implementations on the macro level, such as immediate investments. Finally, the site can lead as an example as one of many knots in the future network of a more sustainable and climate adaptive Hamburg.

SPONGE CITY HAMBURG

As a city that is located closely at and linked to extended areas of water, implementing sponge city principles is part of Hamburg‘s strategy in making the city more resilient. To do so, the city initiated the founding of RISA, an office dedicated to combating climate change and implementing measures to protect the citizens from extreme weather events (RISA Hamburg, 2025a). RISA is one of the core pillars of Hamburg‘s strategy to implement sponge city principles and focuses on four goals:

- Promoting a natural water balance
- Protecting water bodies through the treatment and retention of stormwater
- Heavy rainfall preparedness
- Using rainwater as a resource (RISA Hamburg, 2025b)

In February 2025, Hamburg’s senate introduced a renewed climate adaptation strategy that sets out priorities such as comprehensive coastal and inland flood protection, improved heavy rainfall preparedness, and the citywide implementation of blue-green infrastructure. One major aspect of this approach is identifying vulnerable urban hotspots to better focus adaptation efforts (RISA Hamburg, 2025a). This strategy builds on Hamburg’s long-term “Aktionsplan zur Anpassung an den Klimawandel”, first initiated in 2011, which has since evolved into a dynamic framework. It spans across multiple sectors, including green urban design, infrastructure resilience, and decentralized stormwater management systems like those under the RISA-led “Regenwasser 2030 plan”. These efforts align with sponge city principles by emphasizing infiltration, retention, and evaporation to manage rainfall onsite and prevent urban flooding. Hamburg’s action plan not only supports the implementation of technical and nature-based solutions but also encourages adaptive governance and interdepartmental collaboration (Freie und Hansestadt Hamburg 2013).

In addition to these endeavours, Hamburg is also working on the “Green Network Plan”, aiming to create a network of green places that are eventually fully connected through bike lanes and pedestrian pathways with the goal to ultimately make cars redundant in the city (Hamburg.com, n.d.). This network is being developed piece by piece, through locally anchored interventions. This is precisely where the present project finds its relevance: as a small yet integrated part of this larger green network, implementing sponge city principles at the neighbourhood scale.

Expanding this Network doesn‘t come without its challenges though. While especially small communities throughout Germany struggle with financing these projects, cities like Hamburg find themselves still in the early stages of collecting the data that is necessary to manage and maintain green infrastructure long term (OECD, 2022).

While the sponge city concept primarily addresses challenges related to water management and urban flooding, cities like Hamburg must also consider the compounding effects of rising temperatures. To create truly resilient urban spaces, it is essential to also address the phenomenon of Urban Heat Islands (UHI), as outlined in the following chapter.

URBAN HEAT ISLANDS

The Urban Heat Island Effect (UHI) describes a phenomenon thereby temperatures of surfaces, above ground and the atmosphere of urban spaces are higher compared to rural areas. Commonly, the built environment in our cities has adverse effects on the energy-balance from the sun’s radiation. Structures like buildings and sealed surfaces, found in cities, usually store and release more heat than vegetated natural landscapes, creating a temperature discrepancy between the inner dense core of a city and more suburban and rural spaces outside of town (EPA, 2025).

A more detailed analysis of materials that can aid in UHI mitigation will be conducted in the following chapter and a summary can be found in appendix B.1 and B.2.

HEAT STRESS

Human Health

Thermal stress, especially during periods of heat waves, is linked to several heat-related illnesses, eventually also increasing mortality. Especially elderly people are found to be at risk of suffering from heat-related health risks (Gabriel & Endlicher, 2011). Between 2018 and 2020, Germany was facing a time-period with higher than usual summer temperatures, leading to approximately 19.300 heat-related deaths (Winklmayr et al., 2022). This issue is further exacerbated by higher temperatures linked to the UHI (Abrar et al., 2022). As an additional side effect, the UHI intensifies during heat waves, increasing temperatures even more and prolonging hot conditions (Zhao et al., 2018a).

Yet, the World Health Organization (WHO) refers to a healthy city as "one that continually creates and improves its physical and social environments and expands the community resources that enable people to mutually support each other in performing all the functions of life and developing to their maximum potential" (WHO, 2024). By this definition, it is essential to transform our cities with mitigation strategies for high temperatures in mind.

Pedestrian Thermal Comfort

The thermal sensation of the environment manifests in the human organism through extensive heat exchange between the body and its surroundings. This is not only influenced by numerous meteorological parameters (e.g. air humidity, wind speeds, air temperature, mean radiant temperature) but also by the bodies regulatory system, e.g. sweating on a hot day. This sensation can effectively influence human decisions (Höppe, 1999). Several heat-balance models have been derived over the last decade to effectively quantify on the thermal comfort experienced. Some of them include the PET (Höppe, 1984) or UCTI (Jendritzky et al., 2007), which is effectively being utilized by Ladybug tools in ©Grasshopper (El-Bahrawy, 2024). These tools were designed to provide planner and designer with easily accessible software for informed design decisions regarding microclimate (Roudsari & Pak, 2013).

Highlighting the impact of thermal comfort on urban spaces, Jia et al. (2022) have been able to link an increase of thermal stress to a significant decrease in walking speeds, reducing the walkability of a space. When a space is thermally comfortable, people tend to spend more time outside, while an uncomfortable climate disqualifies space for users and limits their choices of activities in this space. This not only reduces a spaces accessibility but may also have negative effects on social cohesion and interaction (Boumaraf & Amireche, 2021). Thereby, pedestrians prefer to walk, sit and stand in places of high thermal comfort, highlighting the need for a strategic microclimate management (Kim & Brown, 2022).

Average global temperatures are expected to climb by up to 4.8°C until 2100.
-IPCC, 2014

DETERMINING CAUSES

Key causes for UHI can be categorized into a) "Urbanization and population growth", b) "Increased use of manufactured materials" and c) "Elevated heating and cooling demand" (boulnaga et al., 2024: 293 f.). The ongoing urbanization increases the need to expand on built structures, leading to less natural modifications in land use and urbanized surfaces. Similarly, manufactured materials, such as extensive pavements, are used increasingly to keep up with urbanization, yet they are known to have heating properties. Ultimately, the already increased temperatures from climate change and the UHI lead to anthropogenic responses to elevate thermal discomfort (Aboulnaga et al., 2024).

A combination of these effects can lead to temperature differences of up to 7°C in some cities (Lauwaet et al., 2015). Comparably, the city of Hamburg, with extensive water bodies and green spaces, only sees a general temperature difference of up to 1,6°C. Yet, during extended heat waves, differences of up to 6°C have been measured. Here, it should be noted that rural measurements were taken at the local airport, likely minimizing the actual UHI for Hamburg (DWD, 2021).

Geometry
The urban layout and geometry are a crucial factor in changing the local microclimate. Especially an increase in building plan area increases maximum temperatures, while higher buildings alleviate thermal exposure through additional shading (Li et al., 2020). On the other hand, places with less shading can be more comfortable on colder days. Additionally, urban geometry can block wind ventilation, which has negative impacts on pollution dispersion and the thermal experience. While reduced wind speeds are found to be uncomfortable on days with high temperatures, they are favourable on colder days (Krüger et al., 2011). Therefore, a good design should provide comfortable spaces under cold and hot conditions.

Urban surfaces and materials
Vegetative surfaces are decreasing in many places, being replaced by the built environment and the necessary construction materials. Their thermal, radiative and hydraulic characteristics differ from more natural surfaces like vegetation and water. Therefore, the energy consumption promoting vegetative evapotranspiration is lowered, warming surfaces and the air (Grimmond, 2007). It is suggested that asphalt can reach surface temperatures of over 60°C, increasing ground air temperatures in turn (Higashiyama et al., 2016) due to their low albedo and high thermal mass (Qin, 2015a).

Consequently, "cool pavements" are designed to reflect more solar radiation, enhance evaporative cooling or store less heat (Wang et al., 2022). As pavements are utilized in the thermal comfort simulation (see Methodology, p. 58), it is necessary to investigate specific characteristics of cool pavements. The literature distinguishes four main categories of materials, using different techniques:

1. Reflective Pavements

Arguably the most common strategy is increasing the albedo effect of a pavement. Techniques to increase reflectiveness of a pavement are the application of light-coloured aggregates or coatings to asphalt surfaces using white or off-white cemen-

Ill. 11. Example of paved space at the project site
Source: Own Image

titious materials (Quin, 2015b) Qin (2015b) further establishes that the application of chip seals and slurry seals can increase the albedo up to 0.20 and reduce surface temperatures as much as 10-15°C (Kinouchi et al., 2004; Pomerantz et al., 1997). The use of reflective concrete pavements that utilize slag and white cement can even achieve albe-

dos of 0.70-0.80 which provides significant heat absorption (Levinson and Akbari, 2002).

2. **Evaporative and Permeable Pavements**

A different approach to cooling the surface temperature is utilizing water retention and permeability of a pavement (Qin, 2015b). Permeable concretes or asphalts store water and use the cooling effect of evaporation to achieve surface temperature reductions of up to 4-12°C (Haselbach et al.,2011)

3. **Heat storage Modifications with PCMs**

Phase change materials (PCMs) like paraffin wax can be integrated into a pavement and through the absorption of latent heat during phase transition (e-g melting) limit the rise of surface temperature (Wang et al. 2022).

4. **Polymer-Base Solar Reflective Coatings**

Coatings for asphalt pavements that utilize polymer matrices like epoxy or acrylic resins that contain NIR-reflective nanoparticles offer a significant reduction in surface temperature of 8-20°C (Wang et al. 2022; Li et al., 2013a; Santamouris et al., 2011)

These various methods don't come without downsides though. The correct application of coatings and composition, regular maintenance of permeable surfaces to prevent clogging or UV damage of polymer-based coatings over time are difficulties to consider when applying these technologies (Qin, 2015b; Li et al., 2013a; Wang et al. 2022).

Further, objectively, smooth surfaces with light colours have higher albedos and promote colder temperatures. Yet instead, darker materials like asphalt are prevalent in cities (Doulos et al., 2004). However, planner and designer should still be mindful when adopting light materials as a general solution, because, while decreasing immediate surface temperatures, reflected radiation from pavement can lead to higher temperatures of the surrounding built environment, reducing the benefits of reflective materials (Qin, 2015a; Yang et al., 2015). Therefore, aligning with Hayes's et al. (2022), it is key to integrate nature-based solutions engineered surfaces modifications.

Anthropogenic heat flux

Increasing temperatures from global warming and UHI increase the energy consumptions of buildings to maintain comfortable indoor temperatures. For each degree of temperature rise, following a local specific comfortable level, the electricity demand may rise between 0,45% and 4,6% (Santamouris et al., 2015). Conversely, higher power usage for cooling also increases air temperatures (Grimmond, 2007).

THERMAL COMFORT IN URBAN AREAS

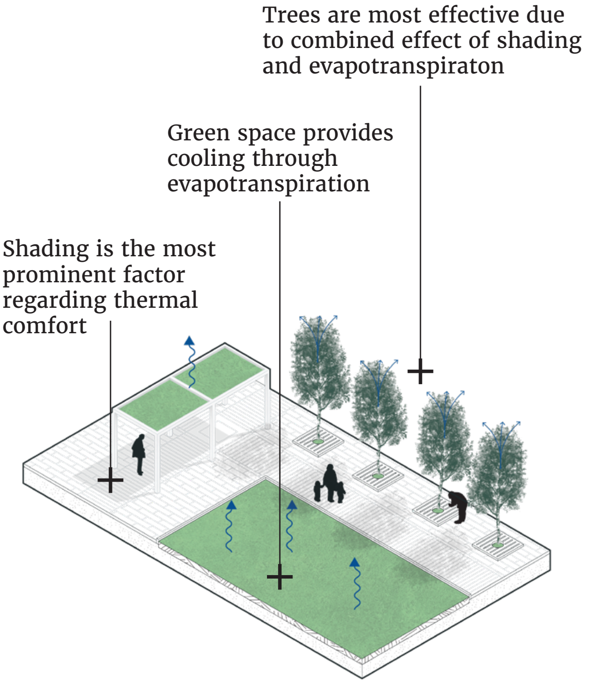
The following chapter presents key aspects regarding thermal comfort in urban areas, derived from the literature. It provides practical design suggestions to mitigate UHIs and therefore create more comfortable urban environments.

Evapotranspiration & Shading

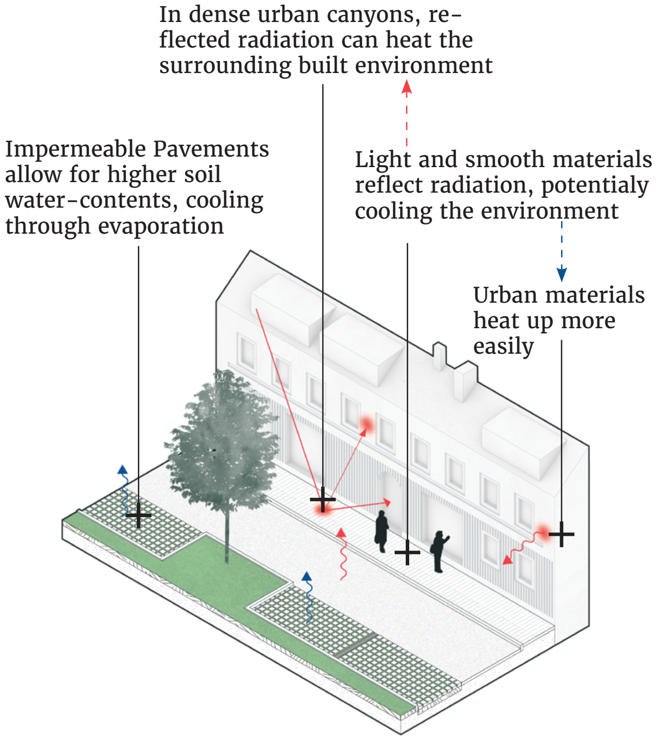
Shading provides the most benefits to thermal comfort by blocking solar-radiation and keeping surfaces cool (Perini & Magliocco, 2014). Although the building layout in developed areas is pre-determined, small shading structures and trees can be utilized. Here it should be noted, that strongly shaded areas lead to discomfort on cold days (Krüger et al., 2011). For designers, trees are the most effective tool by combining shading with vegetative evapotranspiration (Hiemstra et al., 2017). In general, an increase in density of vegetation has profound cooling benefits (Jansson et al., 2007; Perini & Magliocco, 2014). However, the effectiveness is closely linked to soil moisture, making a local water-management advisable (Fini et al., 2017). Also, planting trees in equal intervals and without canopy overlap reduces the number of trees needed (Zhao et al., 2018b). Even so, uncontrolled root growth in the vicinity of built structures and the mitigation of sunlight on lower vegetation is of concern (Balder et al., 2018).

Urban Materials

Green space in urban areas is commonly decreasing in cities and being replaced with urban surfaces (Grimmond, 2007). Although light and smooth materials with high albedos provide more cooling benefits by reflecting solar-radiation, common urban materials, like asphalt, tend to be darker and hotter (Doulos et al. 2004). Yet, polymer-base solar reflective coatings can be applied to existing dark materials, increasing their respective albedo and reducing temperatures by up to 20 °C (Wang et al. 2022; Li et al., 2013a; Santamouris et al., 2011). Nevertheless, reflected radiation can be absorbed and released by the surrounding built environment that uses dark materials, subsequently reducing thermal comfort. The effect is exacerbated in dense urban canyons due to energy being trapped between buildings (Qin, 2015a; Yang et al., 2015). Ultimately, a different solution is provided by permeable pavements. Though not as effective as open soil, these cool through the evaporation of stored water (Fini et al., 2017).



Ill. 12. Evapotranspiration & shading and its effect on thermal comfort
Source: Own Image



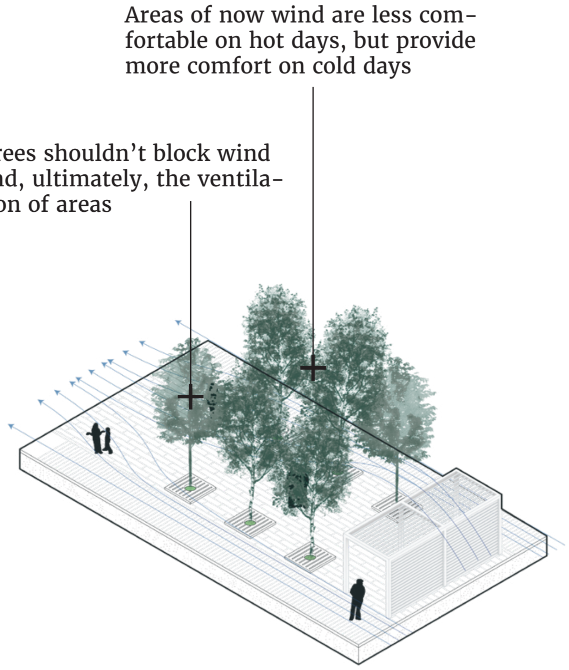
Ill. 13. Urban materials and its effect on thermal comfort
Source: Own Image

Wind & Obstacles

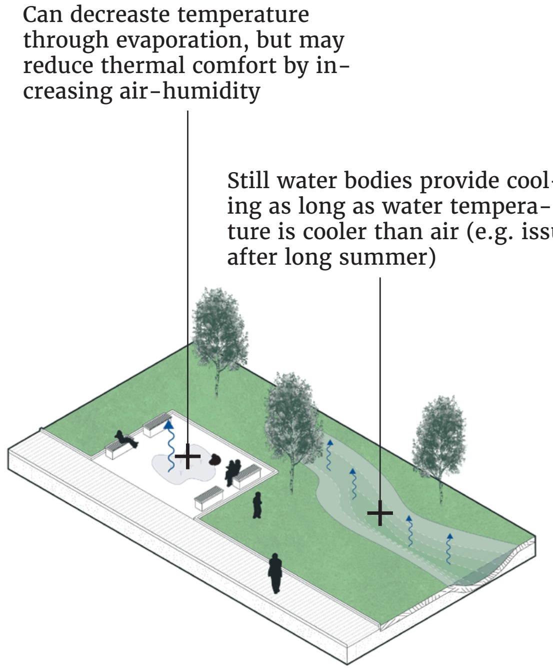
Air velocity, or wind, is an important factor in determining the heat-balance of individuals and their respective sensation of thermal comfort. As such, high air temperatures feel colder on windy days and vice versa (Höppe, 1999). This makes it essential to assess local wind conditions and design areas with specific thermal properties. While good air ventilation of an urban space allows for better thermal comfort on hot days, the opposite is true for cold days. Essentially, urban geometry can be used to guide airflow (Krüger et al., 2011), though this is highly limited in already developed urban settings. However, trees can be used as a tool to change airflow on pedestrian's height. On hot days, airflow should not be impeded by trees to create thermally uncomfortable bubbles of no airflow (Zhao et al., 2018b).

Water Bodies

Open water basins are a common design asset for sponge city developments, storing water locally and slowly releasing it (WBDG, 2025). Water bodies lead to an increase in evaporation, reducing temperatures and therefore improving thermal comfort. However, they can increase the relative air humidity of surrounding areas, which mitigates the positive effect on thermal comfort (Teshnehdel et al., 2022; Theeuwes et al., 2013). In other circumstances, water bodies have shown to heat up during the day, releasing the stored heat at night and decreasing thermal comfort during tropical nights. Moreover, when water temperatures exceed air temperatures, the surrounding area is heated, rather than cooled. This could especially be an issue for smaller water surfaces after long, hot summers (Theeuwes et al., 2013). While open water bodies can be used to reduce thermal comfort, their use should be circumstantial and evaluated against the local setting.



Ill. 14. Wind & obstacles and its effect on thermal comfort
Source: Own Image



Ill. 15. Water baodies and its effect on thermal comfort
Source: Own Image

OPTIMIZING DESIGN DECISIONS

As cities become more-and-more densified, the densification leads to a loss in green space due to conflicts with other uses. Modern green and sustainable design, as well as the introduction of greening standards, are regarded as possible solutions to vegetate more space (Haaland & van den Bosch, 2015).

Anyhow, with increasing complexity of structures and processes, architects lack the necessary knowledge for optimized and integrated designs. Instead, new specialists, like engineers take over the process of development and designs may no longer be developed holistically. Rather, different technologies and solutions are summed on top of original intended designs to meet specified performance standards (Shi & Yang, 2013). For reference, the implementation of sponge cities requires extensive knowledge about hydrology, urban processes and ecological effects (Nguyen et al., 2019).

As a result, the notion of performance-based design is increasingly adopted by architects, where the traditional aspects of aesthetics are combined with physical, measurable performances as determinants for the success of a design. Especially environmental designs benefit from this paradigm (Shi, 2010). On a logical level, the process of designing can be abstracted as exploring a specific design space, consisting of possible solutions. These are based on set objectives, constraints and adjustable variables, thus creating vast opportunities for the architect to investigate (Maher, 2000). Eventually, the development and exploration of numerous possible solutions by hand is time-consuming, whereas computer-based approaches allow to quickly generate and evaluate well-performing scenarios (Geyer et al., 2015). Comparably, conventional architecture only focuses on non-quantifiable decision-making, relying on the architects rational thinking (Shi & Yang, 2013). Despite its benefits, new challenges, such as knowledge about coding and specialized software, are faced by architects (Shi, 2010). Additionally, a lack of information during early design phases hinders the performance of computer-models and its -reliability. Eventually, these issues can be reduced by combining simulation with the critical thinking of architects. As basic inputs, required for running simulation, may lead to an unrealistic design space, the experience of architects can serve as a first guide during early design stages. Uncertainties (e.g. user-behaviour) regarding results should be recognized. To reduce time further, the most sensitive inputs for the results of simulations should be identified beforehand and attention put towards its optimization. Finally, results should consider several objectives and be treated holistically by architects, still highlighting the architect's importance in performance-based design (Østergård et al., 2016).

Research has shown that the concept of sponge cities and mitigation of urban heat islands has the potential for synergies. Additionally, simulations have been used to quantify the effects of sponge city planning to rainwater-management and the UHI for different sites (He et al., 2019; Hou et al., 2019; Yang et al., 2025).

As established before, both, the concept of sponge cities and the thermal sensation of pedestrians can be measured and quantified for their performance and therefore be used as an indicator when designing. Based on this, this work utilizes a derived multi-objective spatial-optimization simulation for the sponge city concept, introduced by Xie et al. (2022) and the Honeybee-Plugin (Roudsari & Pak, 2013) to strategically enhance the decision-making for rainwater management and thermal comfort during the early design process.

SUMMARY

Sponge Cities are based upon implementing green infrastructures and vegetation, storing water and reusing water, reinstalling natural waterways, and installing permeable pavements to open surfaces, allowing water to infiltrate locally. However, a variety of financial, regulatory, and social barriers limit its implementation on a city scale (see Chapter Sponge City Concept, p. 20f.). As such, there is potential for the city of Hamburg in fulfilling their strategy by realizing interventions on a neighbourhood scale that eventually grow together.

Besides its effect on local rainwater management, there are synergies in improving thermal comfort for pedestrians by implementing more vegetated surface covers, water, and building materials into the urban fabric that provide more natural thermal properties (Grimmond, 2007). Better thermal comfort is linked to the walkability of space or individual decision-making on the usage of space (Jia et al., 2022; Kim & Brown, 2022). A mindful design for Sponge Cities can thereby not only make an urban space more resilient towards managing precipitation, but also improve access for pedestrians to an urban site by mitigating extensive heat.

As discussed in Chapter Urban Heat Islands, p. 22f., and Thermal Comfort in Urban Areas, p. 26f., a plethora of possible solutions exist to improve resilience and pedestrian thermal comfort. However, there isn't one specific solution or tool that fits all situations. Different designs and scenarios must be evaluated for the complex interactions between their ability to manage rainwater and improve thermal comfort. As an example, artificial ponds store water and reduce the amount of peak runoff (Chan et al., 2018), although the impact of open water bodies on thermal comfort can be complex and reduced depending on the time of day, season, or size of the water body (Teshnehdel et al., 2022). Ultimately, the local context, as well as financial and legal limitations, set hard boundaries on possible Sponge City developments for a site (Nguyen et al., 2019; Li et al., 2017). Regardless of these varying limitations, it can be proposed that the implementation of Sponge City principles has the potential to serve the multifunctional purpose of managing surface runoff, as well as creating thermally comfortable urban spaces that promote social interaction.

One possible approach, suggested by Höppe (1999), to address the inherently complex interaction of the physical body with its environment, is heat balance models. To avoid other, more specialized actors taking over the design process, leading to non-holistic designs (Shi & Yang, 2013), architects can adopt a performance-based approach, balancing form and function.

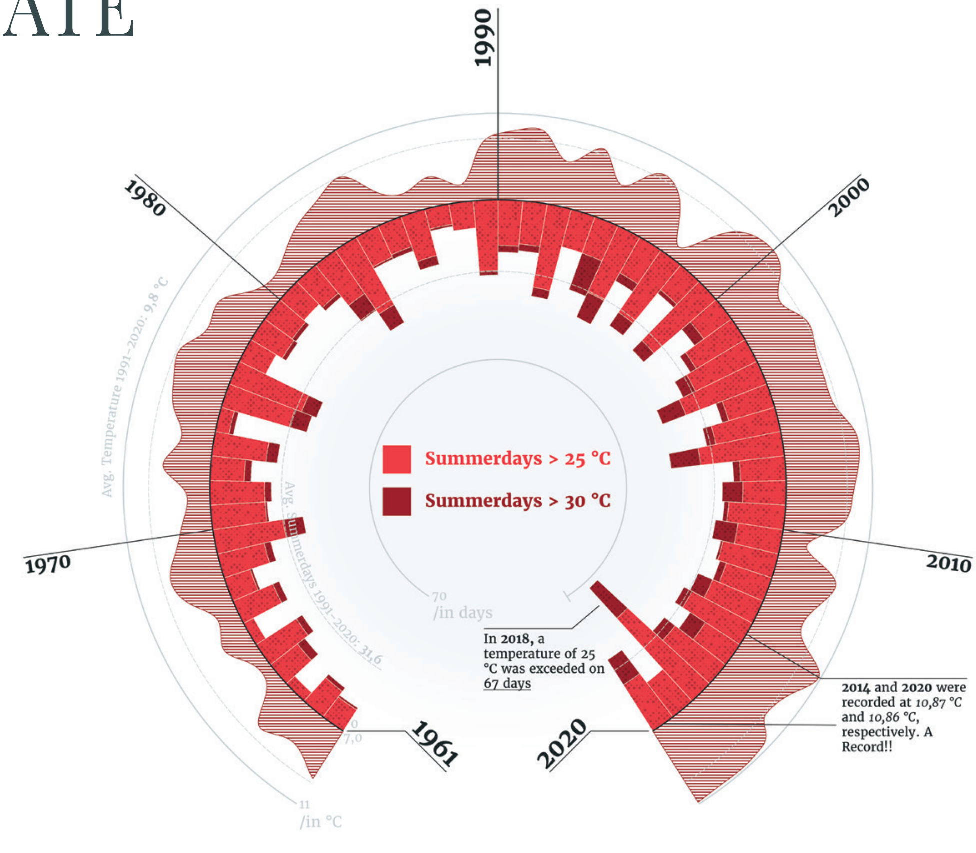
Combined with the analysis conducted in the following chapters, microclimate simulations will be used, following a methodological framework derived from the Integrated Design Process (IDP), to create and evaluate possible scenarios for the case of Gängeviertel, Hamburg.

Ill. 16. Vegetated water retention ditch in Paris
Source: Own Image

SITE AND CONTEXT ANALYSIS

LOCAL CLIMATE

As established in previous chapters, the local climate has a tremendous impact on the effects of microclimate and the thermal challenges pedestrians need to deal with. With the urban heat island effect explaining bubbles of increased heat in the hearts of our cities, architecture can't be taken out of this equation as a problem and solution. Therefore, a responsible design of spaces relies more heavily on monitoring the local climate under current conditions. Additionally, climate change has made it necessary to also evaluate for future changes in climatic conditions and use this as a benchmark for further planning and design (Meir & Pearlmutter, 2010). To unify this process, the Intergovernmental Panel on Climate Change (IPCC) introduced guidelines for expressing possible climate-scenarios, using the Representative Concentration Pathways (RCPs), which are based on varying Co^2-emissions. These RPCs can also be characterized by their estimated temperature increase until 2100, relative to the period of 1986-2005 (IPCC, 2014):



Ill. 17. Average temperatures and number of summer days between 1961-2020, Hamburg
Source: Own Image based on data from DWD (2021: 16f., 39)

- RCP 2.6 – warming to 0,3°C – 1,7°C (CO^2-emissions are lowered now)
- RCP 4.5 – warming to 1,1°C – 2,6°C
- RCP 6.0 – warming to 1,4°C – 3,1°C
- RCP 8.5 – warming to 2,6°C – 4,8°C (continue as it is right now) (IPCC 2014)

When referring to RCPs and estimations on climate change, this report will from here on refer to the explanations given.

Temperature
The average yearly temperature in Hamburg currently stands at 9.8°C for the period of 1991-2020. Compared to the reference

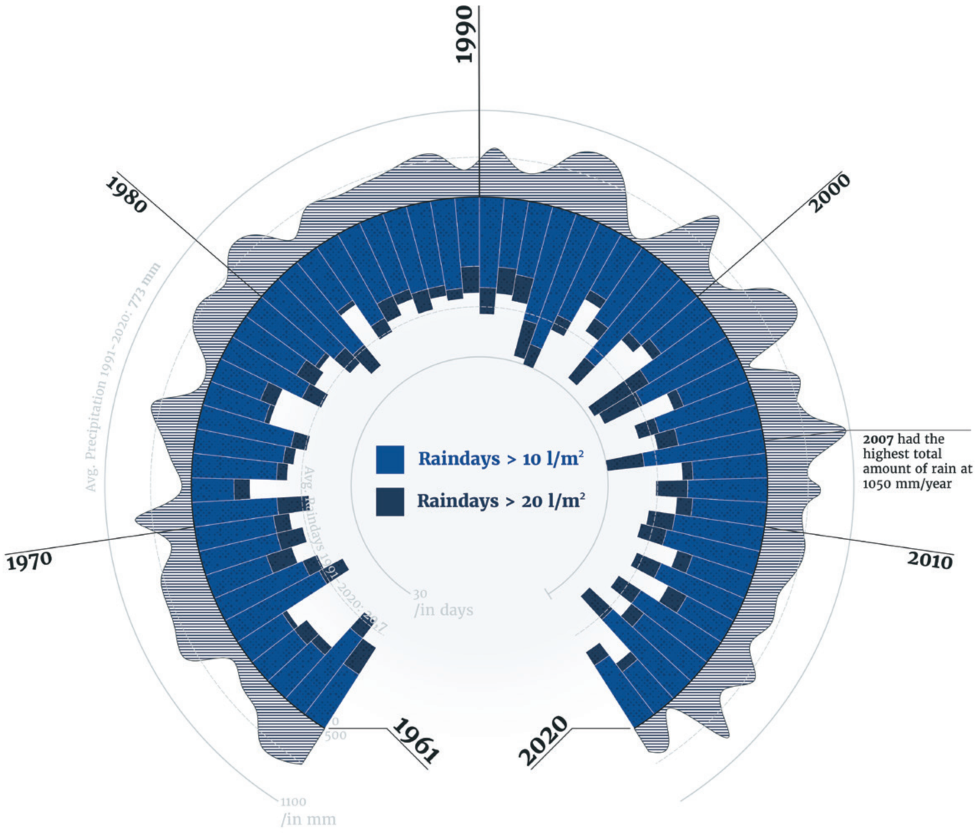
period of 1961–1990, averaging 8.8°C, resulting in a significant increase of a full 1°C in only 30 years (DWD, 2021). To put this into perspective, the average global temperature during the last ice age, roughly 20,000 years ago, was only ~6.1°C lower than it is today (Tierney et al. 2020). This shows the significance and consequences these seemingly small changes in temperature can have on the climatic system. For Hamburg specifically, as seen in Figure X, 2014 and 2020 have overall been the warmest years since weather data has first been recorded in 1881, averaging about 10.9°C (DWD, 2021).

Similarly to the increase in temperature, the city of Hamburg saw an increase in summer days from 21.2 days on average between 1961 and 1990, to 31.6 for the period of 1991–2020. A summer day here is defined as a day where temperatures exceed 25°C. Interestingly, when looking at days of extreme heat (exceeding 30°C), this amount increased from 3 to 6.2, suggesting higher and more frequent peak temperatures in Hamburg (see ill.17).

Overall, there is a linear increase in both the amount of summer days Hamburg faces each year as well as in average temperature. Additionally, days of extreme temperatures have increased substantially (DWD, 2021).

Future Temperature

The temperature for Hamburg is expected to increase a further 1,0 °C to 1,4 °C until 2050. These changes should be considered for dependent planning tasks. For the long-term projection until 2100, the temperature may only increase by 1,1



Ill. 18. Average precipitation and number of rain days between 1961-2020, Hamburg
Source: Own Image based on data from DWD (2021: 20f., 41)

°C for the RCP 2.6-scenario, while the RCP 8.5-scenario results in an increase of 3,6 °C (DWD, 2021). This means that temperature conditions for pedestrians are likely to worsen.

Precipitation

In the recent period of 1991-2020 we have seen an average yearly rainfall of 773 mm. Compared to this, the average yearly rainfall of 1961–1990 was at 750 mm, indicating a small increase of only 3%. As seen in Ill. 18, the amount of rain varies highly from year to year, with the highest amount recorded in 2007, where 1050 mm were measured (DWD, 2021).

Rainy days, defined as days exceeding 10 mm of rain on a single day, have also only increased slightly for the reference period. While 1961–1990 saw 18,1 of such days, the number increased to 20,7 days for 1991–2020. Similarly, the number of days with extrem rain (> 20mm of rain) has only increased from 3,3 to 4,2 days for the reference periods (see ill. 18). Overall, while a linear increase in precipitation can be found statistically, it is ever so slightly and can be neglected (DWD, 2021).

Future

The future-scenarios for Hamburg estimate no significant changes in precipitation. Using the RCP 2.6 and RCP 8.5 scenarios, the total amount of rain only increases by roughly 3% until 2050. Even for the long-term estimation until 2100, the RCP 2.6 estimates a slight decrease of 1%, while the RCP 8.5 results in an increase of 8%. This change is small enough to be attributed to natural climate variability (DWD, 2021).

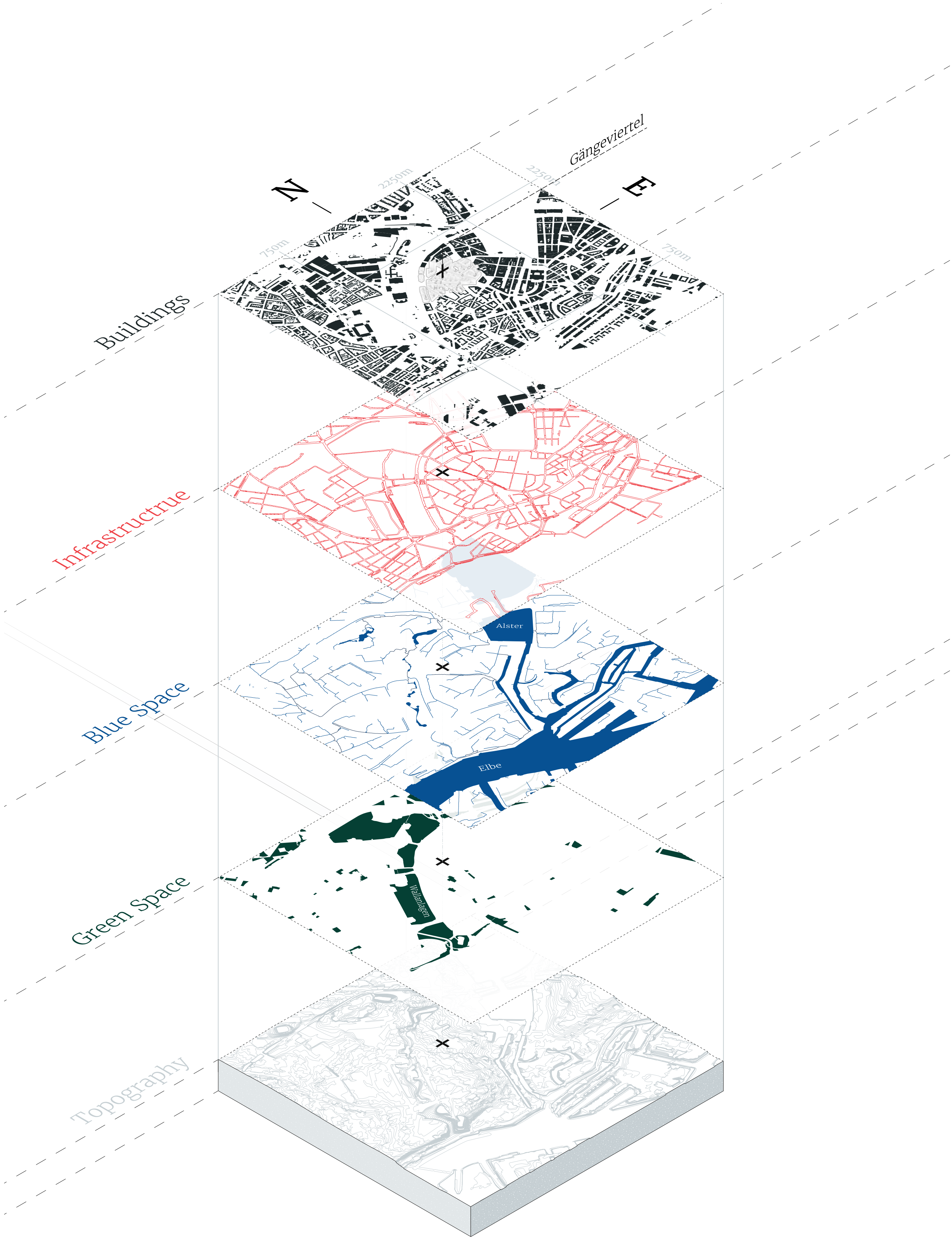
Since precipitation levels are not expected to increase significantly, designing rainwater management systems based on current conditions is appropriate to ensure longevity in this project.

LAYERS OF HAMBURG

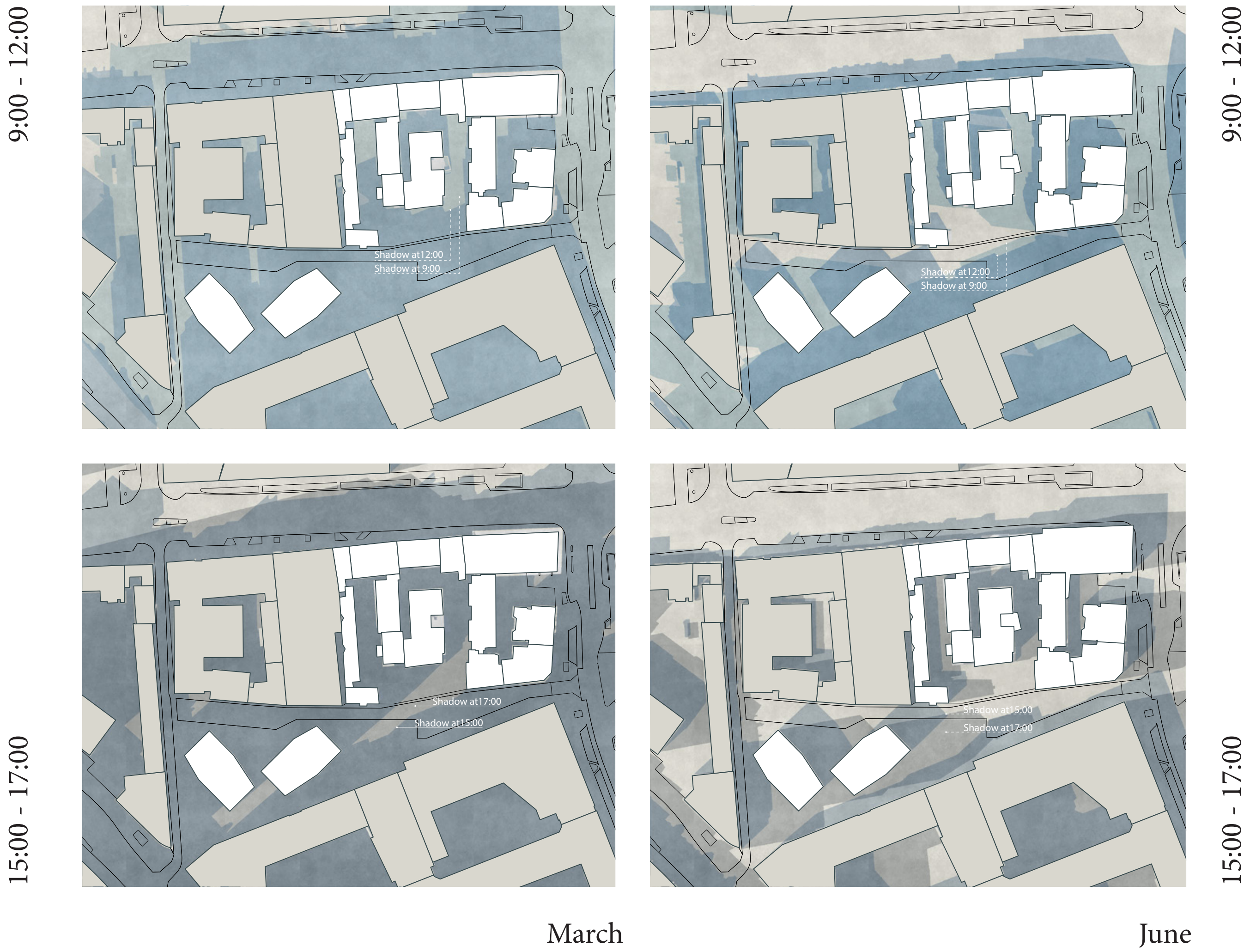
Understanding the location and structural context of Gängeviertel in Hamburg allows for decisions based on the wider urban fabric. As such, a structural analysis has been conducted.

As part of the city-centre, the site is densely surrounded by other buildings. However, there is a wide network of roads leading in and out of the city-centre, giving access to Gängeviertel. The site is thereby encased by roads on all sides (detailed in chapter Roads, p. 43). This dominance of infrastructure and buildings leads to a lack of green space and fits the previously debated densification of Hamburg. The "Wallanlagen", a green belt stretching from the west to the north of the city-centre of Hamburg, is spatially adjacent to the site, however, there is no direct connection. Similarly, while Hamburg's structure is characterized by the "Elbe" river and "Alster", the project site isn't adjacent to any water bodies. In conjunction, Hamburg's topography shows the site being located between the existing blue space, without any connecting flow.

Ultimately, while the site is characteristic for a dense urban core with a network of roads surrounding it, it is also cut off from Hamburg's green and blue space by the surrounding built environment.



Ill. 19. Structural layers of Hamburg
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)
Water Areas- Freie und Hansestadt Hamburg, Behörde für Umwelt und Energie (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Green Areas – Freie und Hansestadt Hamburg, Behörde für Umwelt und Energie (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0, [URI] https://geodienste.hamburg.de/HH_WFS_Gruenplan?SERVICE=WFS&VERSION=1.1.0&REQUEST=GetFeature&typename=de.hh.up:friedhoefe,de.hh.up:kleingartenanlagen,de.hh.up:verzeichnis_oeffentlicher_gruenanlagen (Accessed 14.02.2025)
Elevation model DGM 1 (Changed) - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (LGV) (2021), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/geographie_geologie_geobasisdaten/Digitales_Hoehenmodell/DGM1/dgm1_2x2km_XYZ_hh_2021_04_01.zip (Accessed 14.02.2025)

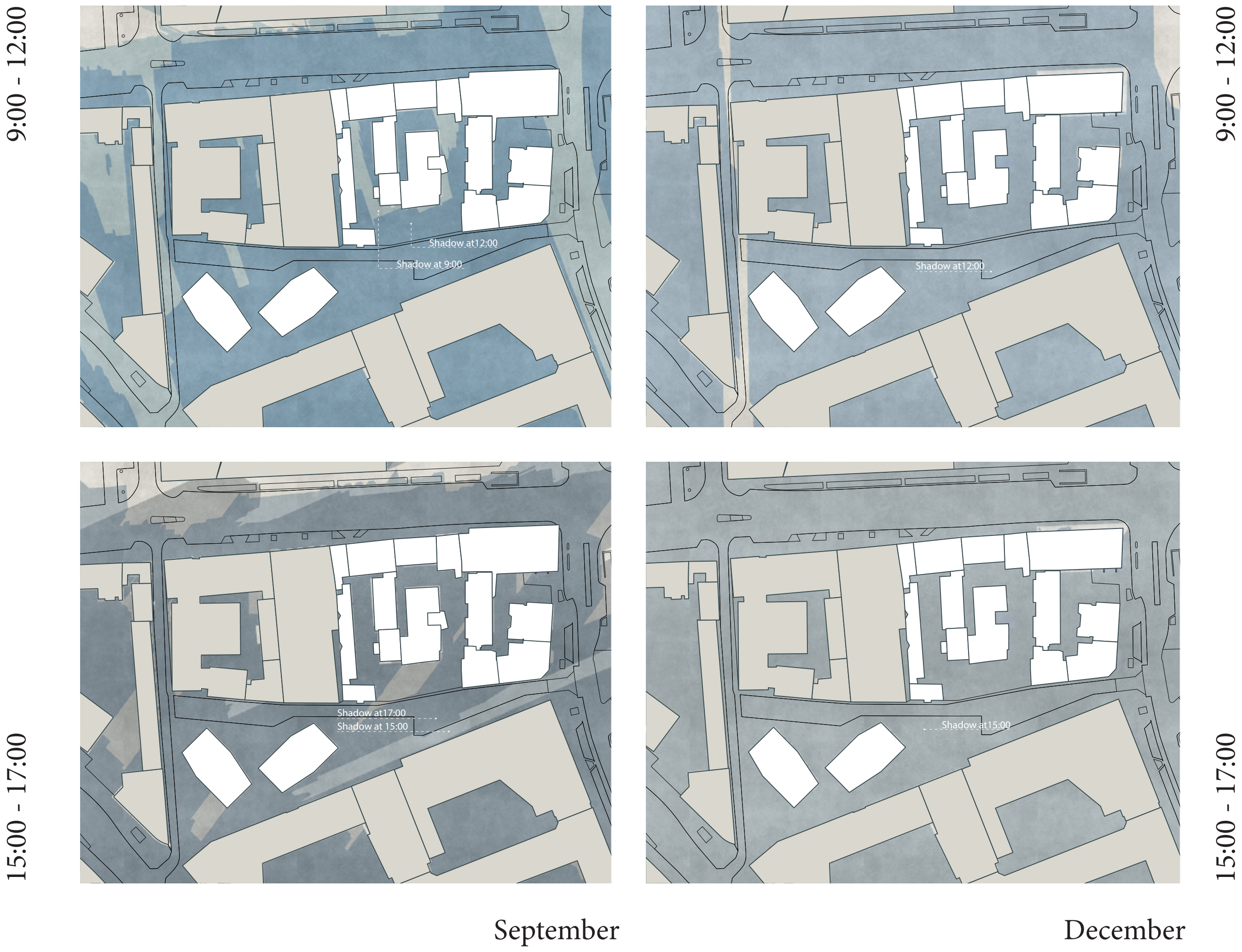


Ill. 20. Shadows at various times of day in March & June
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

SHADOWS

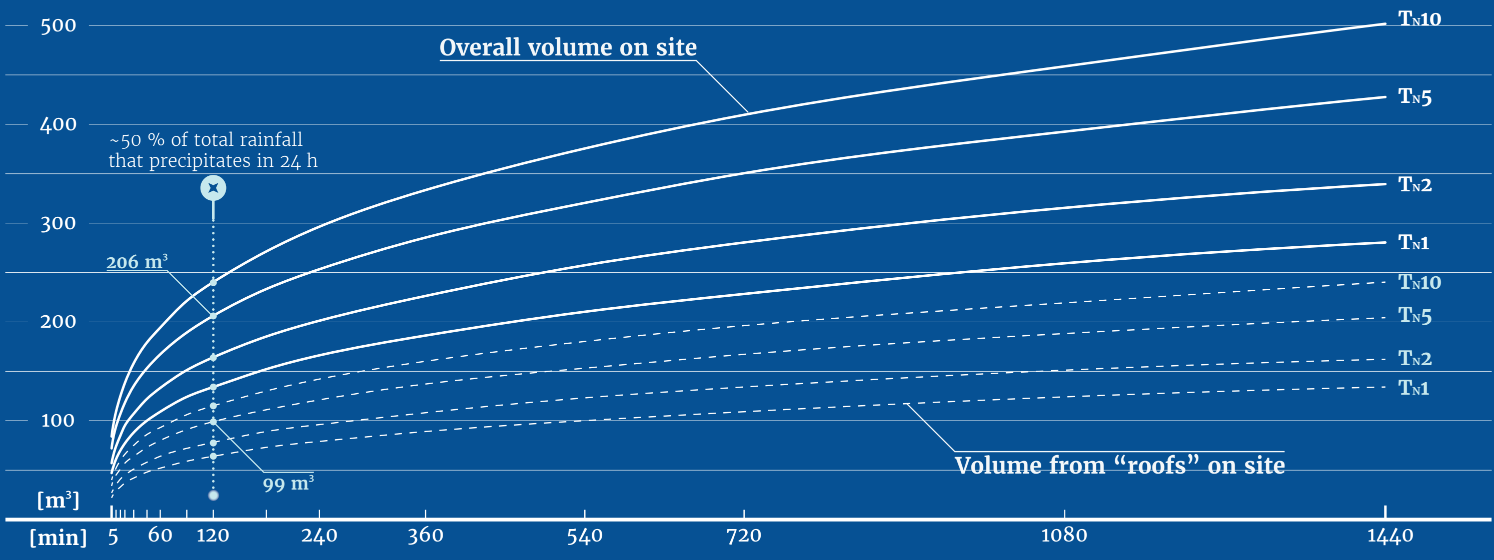
Understanding the course of shadow during a day at different times of the year and the consequent total sun hours is useful to determine if the site might have too much or even too little sun. As established before, it also has a major influence on the local microclimate. Especially in times of climate change and rising temperatures related to it, people tend to prioritize places with sufficient shade coverage and might even change their path to stay in shadow for longer (Kim & Brown, 2022).

To get a clear picture of the shade situation on site, the analysis depicts one day in four different months in the year. As shown in ill. 20-21, each of the diagrams features 2 hours per diagram, split up into 9am and 12am, and 15am and 17am. While the 9am shadow can help understand how cool the site is in the morning, the 12am analysis high-



Ill. 21. Shadows at various times of day in September & December
Source: Own Image
Datasets: see Ill.20

lights shadow distribution at the hottest time of the day. Further, the 15pm and 17pm shadow locations depict the further course of the shadow into the evening. As the analysis indicates, the site is predominantly covered in shadow, which is cast by the tall buildings in the south. Only the open area in front of the historical Gängeviertel allows for significant access to sunlight in June.



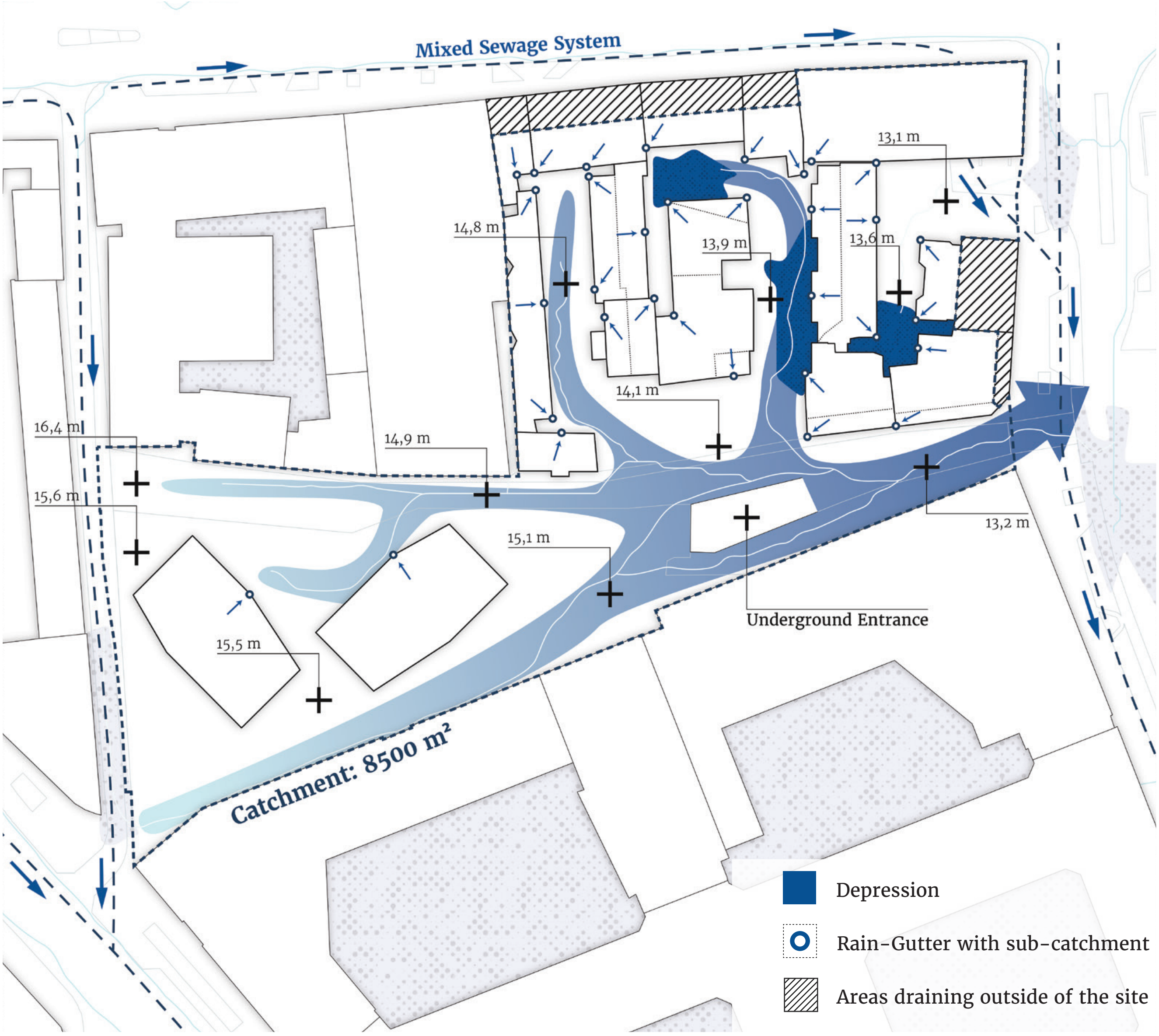
Ill. 22. Rain volume for different rain-events at Gängeviertel
Source: Own image based on data from Deutscher Wetterdienst (2023)

HYDROLOGICAL ANALYSIS

The following chapter analyses the hydrological management at the site, which will be part of the foundation for the multi-objective optimization on rainwater-management systems. For the dimensioning and placement of rainwater-management systems, the analysis must consider the hydrological flow from the local topography and expected amounts of rainwater, as well as soil conditions and groundwater conditions. Moreover, water protection areas must be recognized, as official requirements on rainwater-systems, such as filters to prevent groundwater pollution, are stricter (DWA, 2005; BSU 2006).

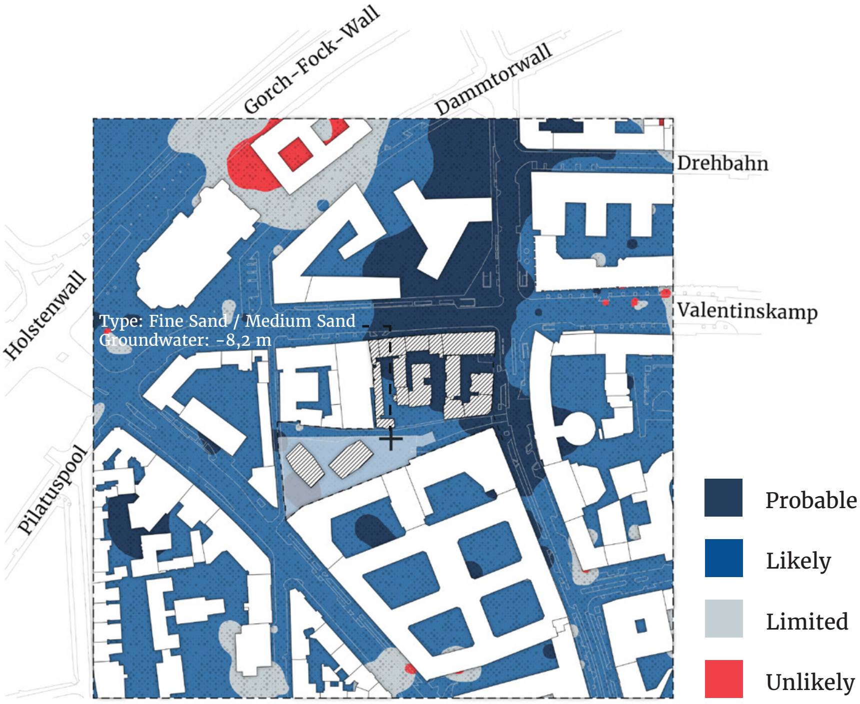
The fixed watershed for Gängeviertel is determined to be at 0,85 ha. Thereby, the amount of rain was calculated using a discharge coefficient for 4 different rain-events at numerous timestamps (see appendix C.3). As some rainwater-management systems are only allowed to receive unpolluted runoff from roofs (DWA, 2005), the partial drain from all roofs was calculated as well. The sub-catchment for all roofs in the area is determined at 0,34 ha (see appendix C.3). Notably, roughly 50% of rain precipitates during the first 2 hours of a chosen rain-event, compared to 24 hours of rain. This means that the intensity drastically decreases over longer periods, reducing the hydrological stress on rainwater-management systems. For a 5-year rain-event at 2 hours, this accumulates to 206 m³ for the whole area and 99 m³ for runoff from roofs (see ill. 22).

In addition to these performance values, Gängeviertel is



Ill. 23. Hydrological analysis
Source: Own image using flow-analysis from Scalgo
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/openda-ta/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)
Elevation model DGM 1 (Changed) - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (LGV) (2021), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/geographie_geologie_geobasisdaten/Digitales_Hoehenmodell/DGM1/dgm1_2x2km_XYZ_hh_2021_04_01.zip (Accessed 14.02.2025)
Sewage System (Changed) – Refer to Hamburger Stadtentwässerung Aör for the ,,Leitungsbestandspläne”

characterized by the topography sloping down from west to east. Water accumulates all over the site and is runs off along the streets, eventually collecting at the centre of the site and exiting at the eastern opening. Natural shallow depressions are scarce yet mostly located at entrances for the building's basements. To be able to understand the flow and origin of the runoff created in more detail, the visible rain-gutters at the site are mapped. Ultimately, there currently is no decentral rainwater-management at the site and runoff is discharged into a mixed sewage system (see Ill. 23). In the event of strong rains, a lack of capacity in these systems not only leads to overflowing rainwater, but also uncleaned household sewage (UBA, 2022). Though the site itself is not in immediate threat to intense flooding, introducing a new type of decentral water-management relieves stress on the sewerage and is part of a holistic water-management. Additionally, guiding the water helps to prevent water flooding the basements at the historical part of Gängeviertel.



Ill. 24. Soil layers and infiltration potential
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)
Infiltration potential - Freie und Hansestadt Hamburg, Behörde für Umwelt und Energie (2018), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/umwelt_klima/versickerungspotential/Versickerungspotentialkarte_HH_2018-06-29.zip (Accessed 14.02.2025)
Drill data - Geologisches Landesamt Hamburg (2005), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://geodienste.hamburg.de/app/render?sid=0x960470caL0x71973d4cL&id=2033336 (Accessed 18.02.2025)

SOIL ANALYSIS

Infiltration is a key component when realizing sponge cities, as stormwater runoff is reduced at the place of rainfall and groundwater levels are replenished. This improves the natural water-cycle and reduces hydraulic stress on grey infrastructures (WBDG, 2025). Yet, site-specific soil conditions heavily impact its ability to effectively infiltrate water and thereby limiting the technical solutions that can be implemented for a decentralized water-management. Additionally, its properties are crucial in cleaning runoff and protecting groundwater reserves from pollution. The optimal rate of infiltration for a soil lies between 1*10^-3 m/s (86,4 m/day) and 1*10^-6 m/s (0,09 m/day). Slower rates lead to near impossible infiltration, while faster rates decrease its cleaning effect. Lastly, the distance to the highest groundwater levels should be at least 1m for infiltration to be considered (DWA, 2005).

The site is characterised by a combination of medium and fine sands (see ill. 24). While exact rates of infiltration could only be measured on-site, DWA (2005) provides approximate values for some soil types. In this case, an estimated infiltration rate of 5*10^-5 m/s (4.32 m/day), combined with deep groundwater levels at approximately -8.2 m, indicates favourable soil conditions.

As suggested by ill. 24, the soil conditions for the whole site are expected to be likely, or better. Conversely, from a conversation with an involved city planner at Gängeviertel, it became apparent that the northern, historical part of the site is likely to have unfavourable soil conditions due to centuries of human building activity (appendix A). For simulation purposes, the infiltration rate here is assumed to be at 7*10^-5 m/s (0,043 m/day). Further, as the project site represents a highly dense urban space, a present underground garage limits infiltration here additionally (see ill. 24).

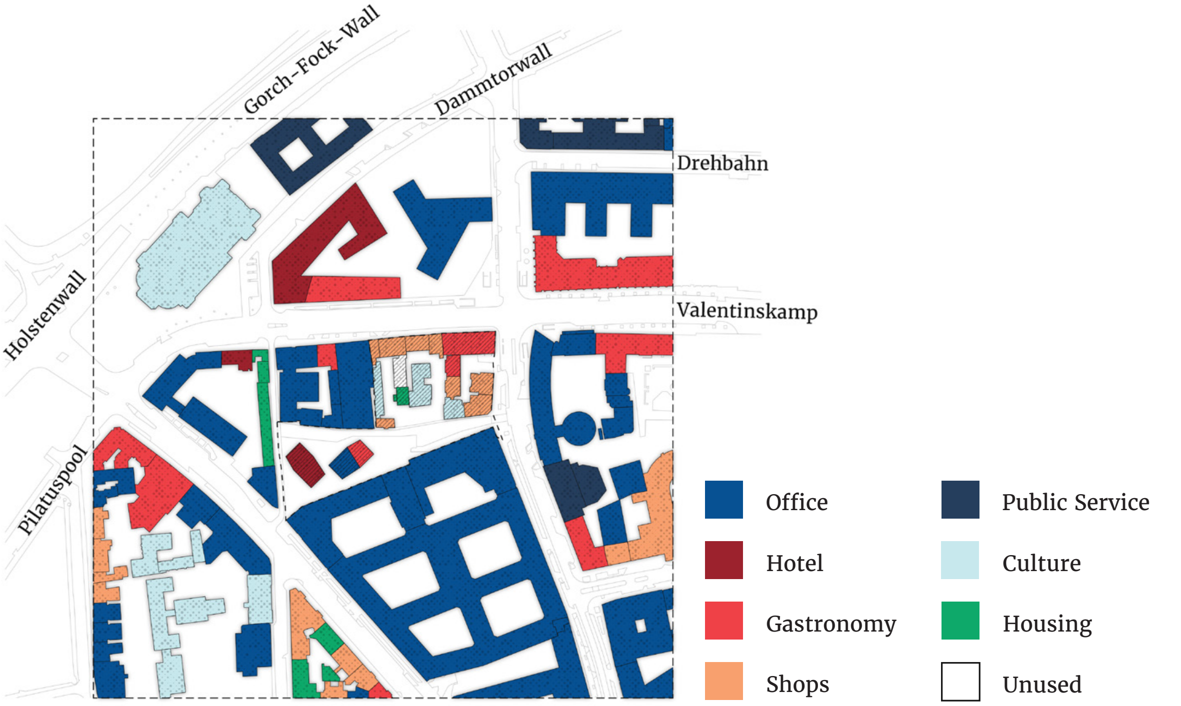
NOISE

One of the important factors in achieving urban comfort is noise. While it‘s not necessarily the pure loudness that causes discomfort, certain polluters, like the noise of traffic, are proven to cause discomfort. Nonetheless, additional factors that need to be considered are the environment in which a loud noise occurs and how accustomed the people in it are to a noisier environment (Yang et al., 2005). Based on the study by Yang et al. (2005), individuals from noisier environments generally find loud settings less discomforting. Additionally, aspects like the aesthetic of a surrounding or its specific thermal and wind conditions play a significant role in overall comfort.

As depicted in ill. 25, the buildings along Valentinskamp Street block noise levels caused by traffic, which times exceed 75 dB. This creates a space inside the Gängeviertel that is protected from noise pollution. The highest measured noise levels are along Kaiser-Wilhelm-Straße to the west of the site, reaching 55–65 dB, and in parts into Speckstraße, where noise levels can reach 55–60 dB. No other sources of sound inside the area that would affect the soundscape of the Gängeviertel are present. However, detailed noise data on Gängeviertel is not available.

These findings highlight the area‘s potential as a place of retreat from the otherwise loud urban environment and underscore the interplay of factors that need to be considered in further planning to reach overall comfort in the site.

Ill. 25. Noise analysis
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)
Noise - Freie und Hansestadt Hamburg, Behörde für Umwelt und Energie (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://geodienste.hamburg.de/HH_WFS_Strassenverkehr?SERVICE=WFS&VERSION=1.1.0&REQUEST=GetFeature&typename=de.hh.up:strassenverkehr_nacht_2022,de.hh.up:strassenverkehr_tag_abend_nacht_2022 (Accessed 01.03.2025)



Ill. 26. Building Functions
Source: Own Image based on data from Gängeviertel E.V. (2015b)
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

FUNCTIONS

Getting an understanding of the ground floor functions of the site's context aids in understanding both, socio-cultural dynamics and spatial relationships on the site. Further, this analysis can shed light on how the Gängeviertel, an area that has been identified as a social hub and place for activists, might be in friction with its surroundings.

While the surroundings are a mix of offices, predominately in the south, some cultural offers in the north, and a blend of shops, gastronomy, and public service functions throughout, only a few buildings could be identified purely for housing. The Gängeviertel presents itself with a blend of functions like its surroundings. This diversity finds itself again in the layered mixed-use typology of the buildings that create a vibrant neighbourhood. Along the Caffamacherreihe and Valentinskamp, buildings are split into studios and residencies used by artists. Commercial uses and spaces for storage are on the ground floor throughout the site, and social spaces can be found along the Speckstraße (see ill. 26). Additionally, the building along the Schlierpassage called "Terrasse" is currently uninhabited due to structural problems in the building (see appendix A).

The layout of the Gängeviertel supports its role as a hub for diversity and creativity and offers great opportunities for tying its surroundings together. In the further design process, a focus should be placed on ensuring that the district doesn‘t create friction with its surroundings due to its socio-cultural dynamics and land use priorities.

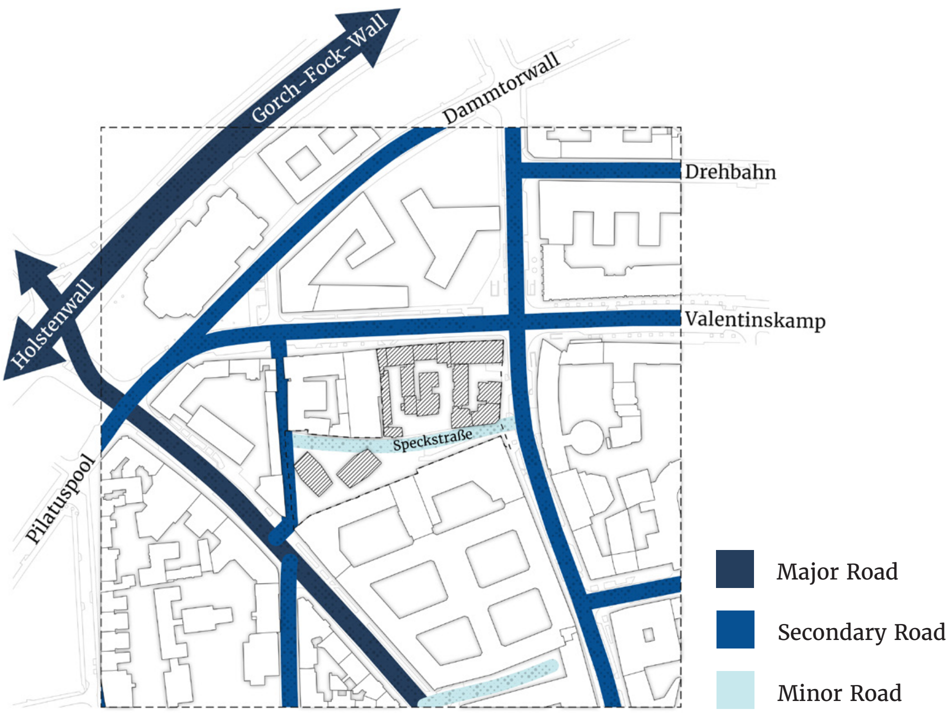
In the further design process, a focus should be placed on enhancing the role of the Gängeviertel and integrating it into the further surroundings.

ROADS

Observing the road network that surrounds the site gives indications on how well a site is connected to its adjacent areas and has further implications for aspects like traffic-related pollution. According to DWA (2005), the availability of road-traffic determines the measurements that must be taken to reduce the pollution of stormwater runoff.

It is worth noting, that the site itself is sheltered by the buildings around it. As indicated in the chapter Noise, p. 41, the area is well sheltered from all major roads. To the north and east, the space is connected via secondary roads that lead, similar to the main road, further into the city centre of Hamburg. Important for this project and the later design phase is the minor road, Speckstraße, that crosses the site from east to west and is private (see ill. 27). A site-visit revealed restricted access to most parts of the Speckstraße, however it must remain intact since it provides access for emergency vehicles and service cars.

While the level of connection from the site to its surroundings is excellent, the main challenge in the later design is posed by the private street, since it can not only be adjusted to a limited extent, but also splits the areas of Gängeviertel and Brahmsquartier, which should be investigated in the further process.



Ill. 27. Road-network, 1:5000
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads - Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

FLOW ANALYSIS

Analysing the flow delivers valuable information on how people move through the space and how efficiently a space is used, which can later be used to guide certain design choices.

Ill. 28 and ill. 29 illustrate the flow of pedestrians through the site in the morning and late afternoon. It is noticeable that there is little to no significant difference between the walking patterns during these two timeframes. Further, the most used path taken by people arriving from outside the area is the path along the office building to the south, where pedestrians have been mapped to travel through the entirety of the site, suggesting its value as a transit space. The least amount of flow was counted from and to the direction of Gängeviertel. Apart from some cars, only a few bicycles were counted, indicating that the project site is mostly used by pedestrians. Finally, worth mentioning is the flow of people that was seen coming in and out of the office building in the south.

Pedestrians counted:

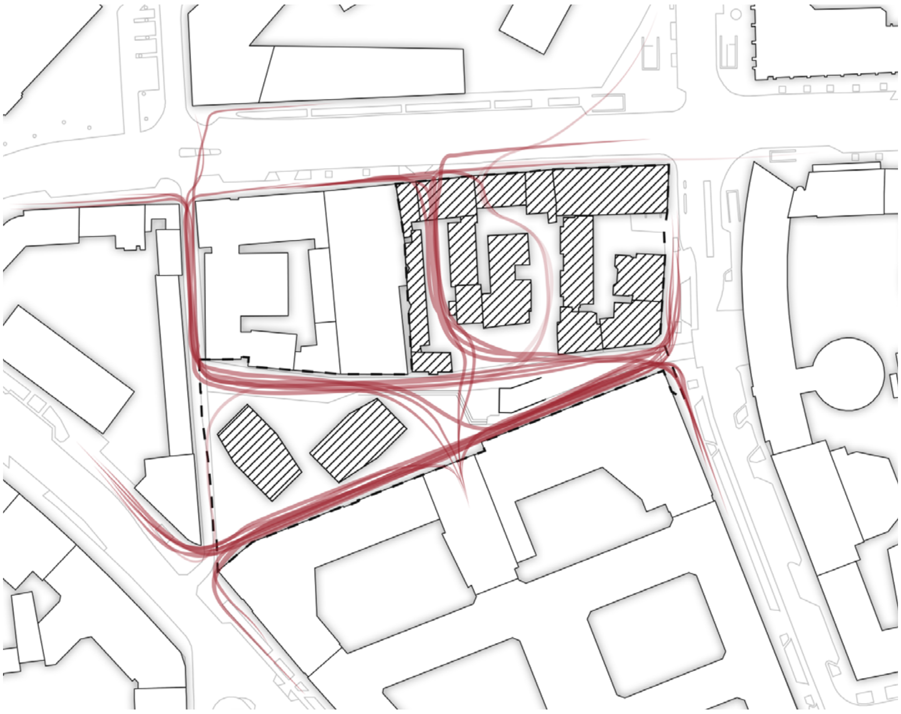
9:00am	17:00pm
104	123

Cyclists counted:

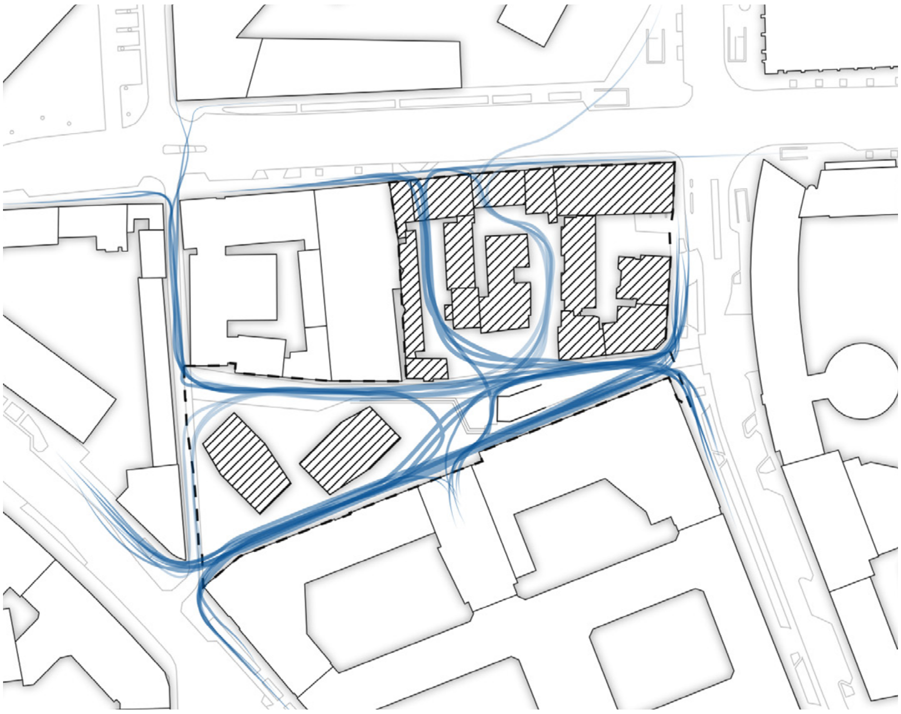
9:00am	17:00pm
5	1

Cars counted:

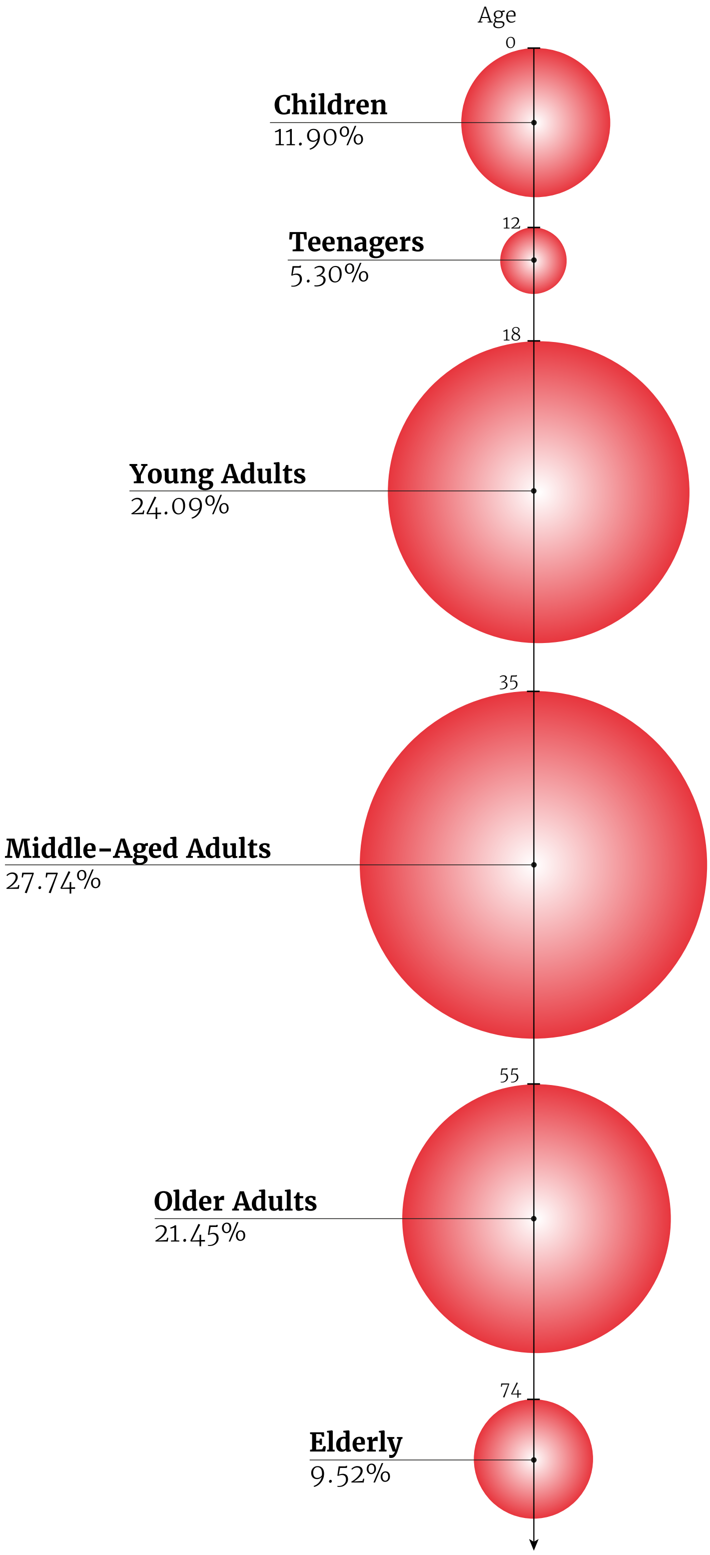
9:00am	17:00pm
2	1



Ill. 28. Flow mapping at 9:00-9:30 am
Source: Own Image
Data Set: See Ill. 29



Ill. 29. Flow mapping at 4:30-5:00 pm
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads - Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)



Ill. 30. Demography of Hamburg
Source: Own Image based on data from Statistikamt Nord (2024a)

DEMOGRAPHY

Analysing the demography of Hamburg and the project site is important because it allows the design to adapt to the needs of its users while giving an indication of who might be using the area and how they shape the urban space around them. This is especially relevant since the project site acts as a cultural hub, seeking to be available for all people.

Hamburg has around 1.9 million residents, with an average age of 41. As depicted in ill. 30, the biggest age group is the 35–54 years bracket (27.74%), closely followed by the young adult age group of 18–34 years (24.09%). Given the nature of the site as both a space for transit and a social hub, many different age groups will be present in the area.

Neustadt, the district of the project site, is inhabited by an estimated 12,500 residents on an area of about 2,200 km², resulting in a density of 5,801 people/km². This makes it one of the most densely populated areas in Hamburg, which has a combined average of 2,500 people/km² (Statistikamt Nord, 2024b).

Because of its density and relative homogeneity, it's important to implement a variation of functions into the space that caters to the need of different age groups.

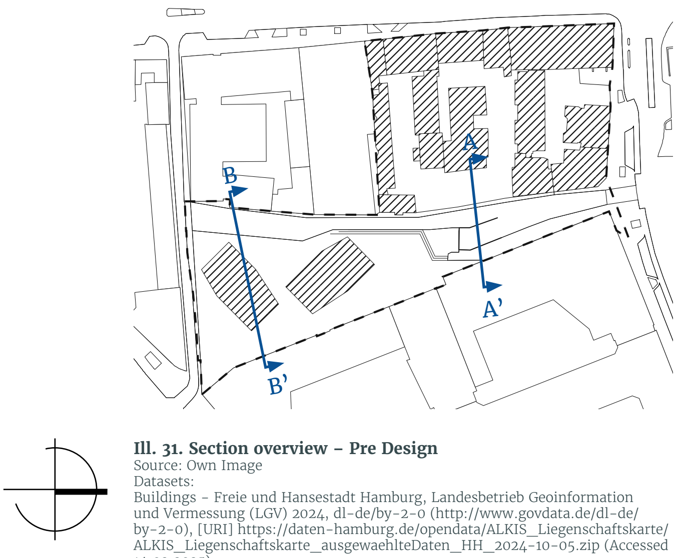
SPATIAL ANALYIS

SECTIONS OF THE CURRENT SITE

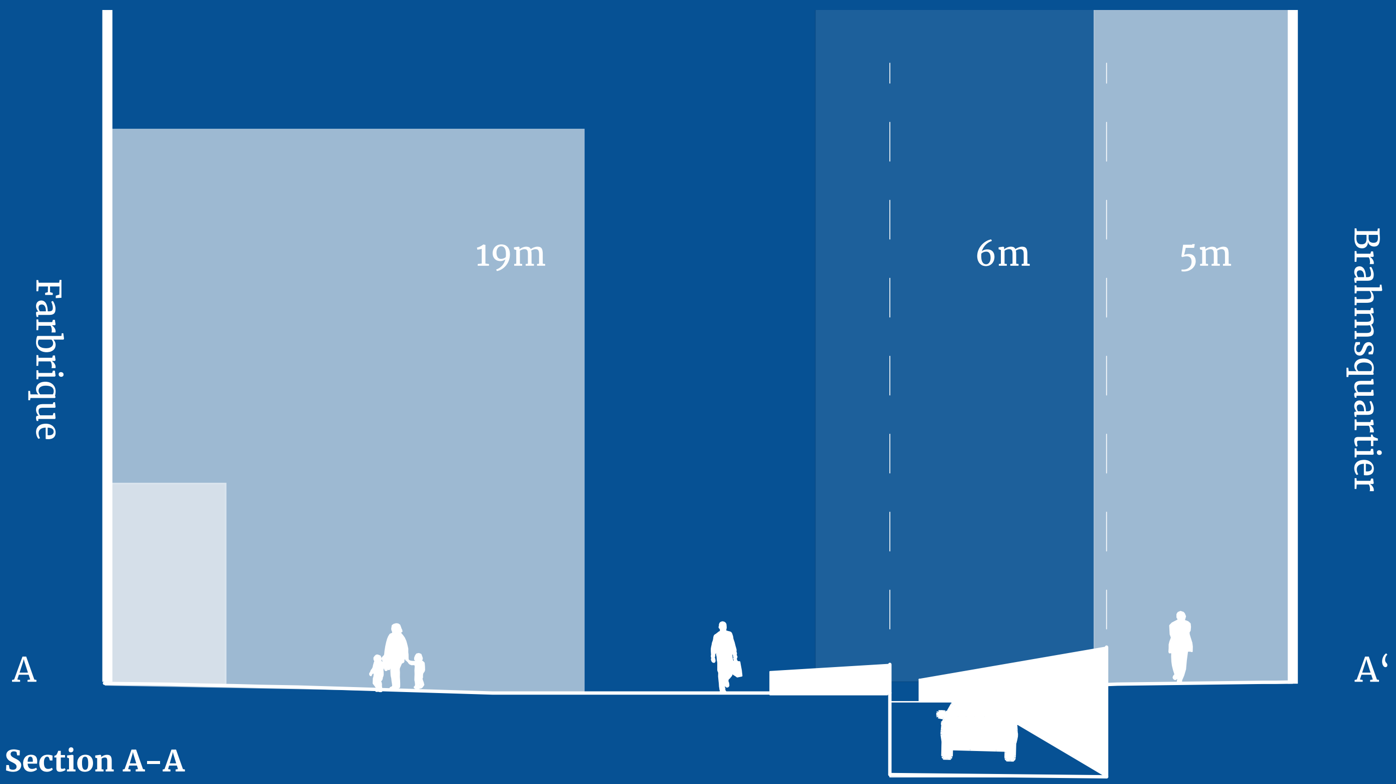
To illustrate both, the spatial relationship between the ground level and the surrounding buildings, and to analyse the site's relationship to human scale, the following sections have been created. This also helps to pinpoint the location of the underground parking.

Ill. 32-33 both cut through the site from north to south, highlighting the openness of the area and revealing the stark contrast between the outdoor space and the tall buildings. Additionally, both sections indicate the large, two-story underground parking structure that stretches along the Brahmsquartier, extending across the entire project area from east to west.

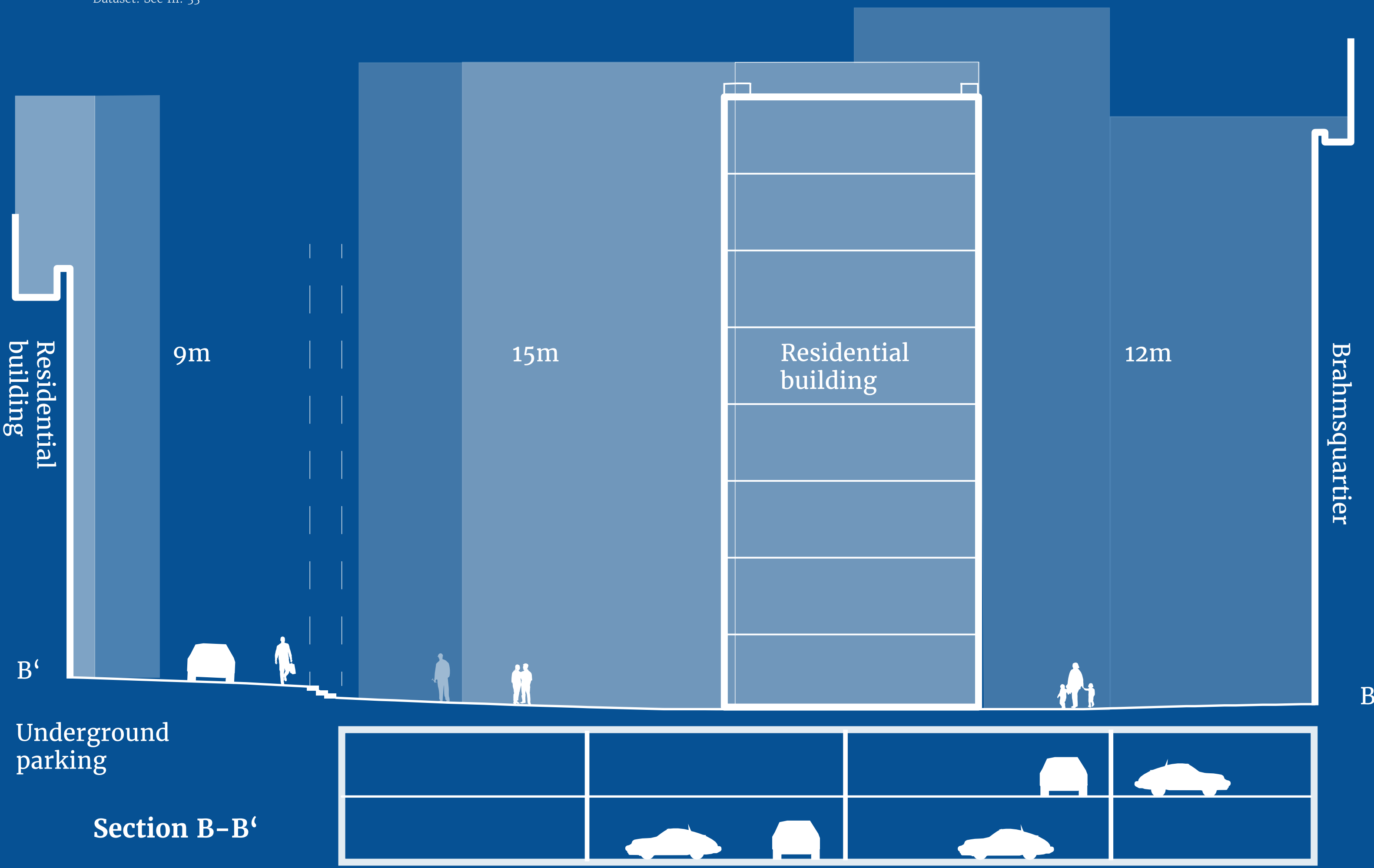
During the upcoming design phases, it will be important to take the underground car park into account, while developing strategies to reduce the openness of the area and create a more human-scale, liveable environment.



Ill. 31. Section overview – Pre Design
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (LGV) 2024, dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads - Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

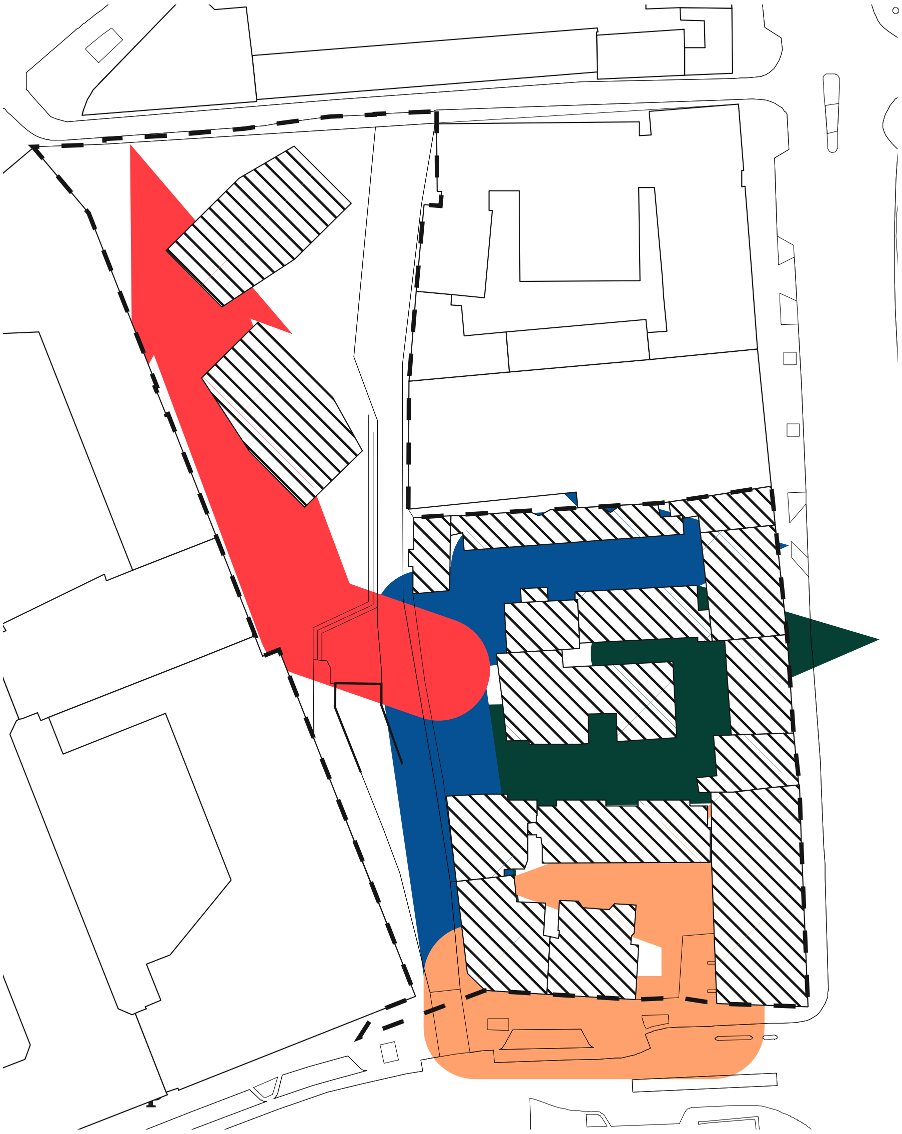


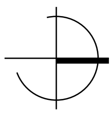
Ill. 32. Section A-A’ – Pre Design
Source: Own Image
Dataset: See Ill. 33



Ill. 33. Section B-B’ – Pre Design
Source: Own Image
Datasets:
3D-Buildings (Changed) – Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2023), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), https://daten-hamburg.de/opendata/3d_stadtmodell_lod3/LoD3-HH_Area1_2023_12_14.zip (Accessed 17.02.2025)
Elevation model DGM 1 (Changed) – Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (LGV) (2021), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/geographie_geologie_geobasisdaten/Digitales_Hoehenmodell/DGM1/dgm1_2x2km_XYZ_hh_2021_04_01.zip (Accessed 14.02.2025)

A WALK THROUGH THE SITE





Ill. 34. Route of walk through
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

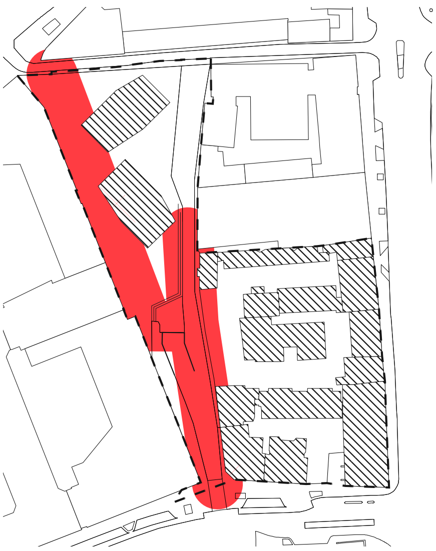
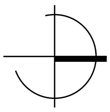
This section presents a sequential visual exploration of the site, divided into four routes that all begin at the site's eastern entrance on Speckstraße. Rather than interpreting the space subjectively, this walkthrough serves as a record of the site's physical character, offering a direct visual understanding of its structure, scale, and atmosphere.


Location:
Bäckerbreitergang



Route Red

Starting at the south entrance of the site, the red route (ill. 36) follows the area of the Brahms-quartier. The first impression is dominated by the entrance to the underground parking that separates the Speckstraße from the pedestrian path along the office building (left in the picture). The otherwise open and heavily paved space continues over stairs to the south-west entrance of the site. The space continues to feel corporate, clean, and formal with minimal vegetation, past uninviting play elements and long glass and concrete facades.

Ill. 35. Walking path / red
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geo-information und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/open-data/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_aus-gewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads - Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

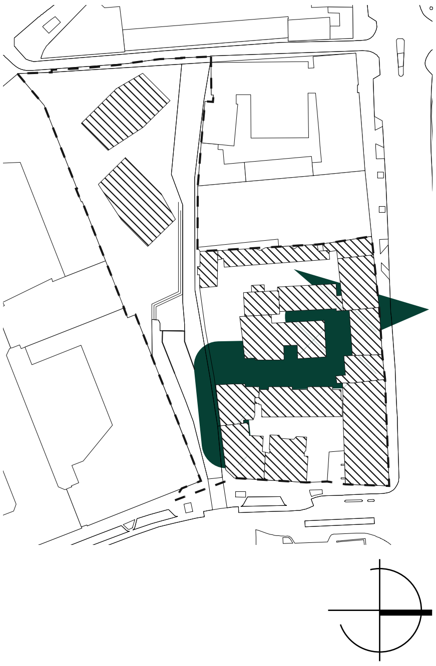



Location:
Speckstraße

Ill. 36. Impressions of the red route
Source: Own Image

Route Green

Starting in an open urban space, graffiti-covered walls contrast with the modern high-rise buildings in the background. Confirming Martin's statements (see appendix A), the site appears to be under construction, reinforcing the DIY character he described. The sequence continues through a mismatched architectural landscape. Reinforcing the community-driven identity, varied architectural styles and a general scattering of objects create a contained and intimate atmosphere. The route then passes into an open space with brick walls, artistic elements, and some urban gardening, before reaching a fork: a left turn leads into a trashed dead end, while continuing forward leads to Valentinskamp street, which marks the northern boundary of the site (see ill. 38)



Ill. 37. Walking path / green
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads - Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

Location:
Valentinskamp

Ill. 38. Impressions of the green route
Source: Own Image

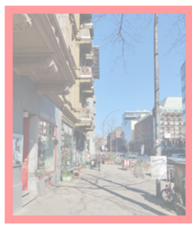
Route Blue

The blue route begins roughly 10 meters west of the green route's starting point on Speckstraße, but maintains a similar visual style. Behind piles of assorted construction debris, graffiti-covered brick walls set the tone for an alternative, community-oriented environment. The path opens into a courtyard that eventually leads to a second exit onto Valentinskamp street. The space is defined by scattered objects and artworks, mixed with greenery and raw urban surfaces (see ill. 40)

Ill. 39. Walking path / blue & yellow
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

Route Yellow

Beginning at Speckstraße, this route turns east, following Caffamacherreihe. Plants, benches, and informal seating create a welcoming atmosphere and give the impression of a socially engaged, artistic community. The walk continues through an open space with a mixed-use character, artistic patterns, and creative interventions, before concluding at a paved dead end near a bike shed adorned with greenery and decorations (see ill. 40).



Location:
Schlierpassage

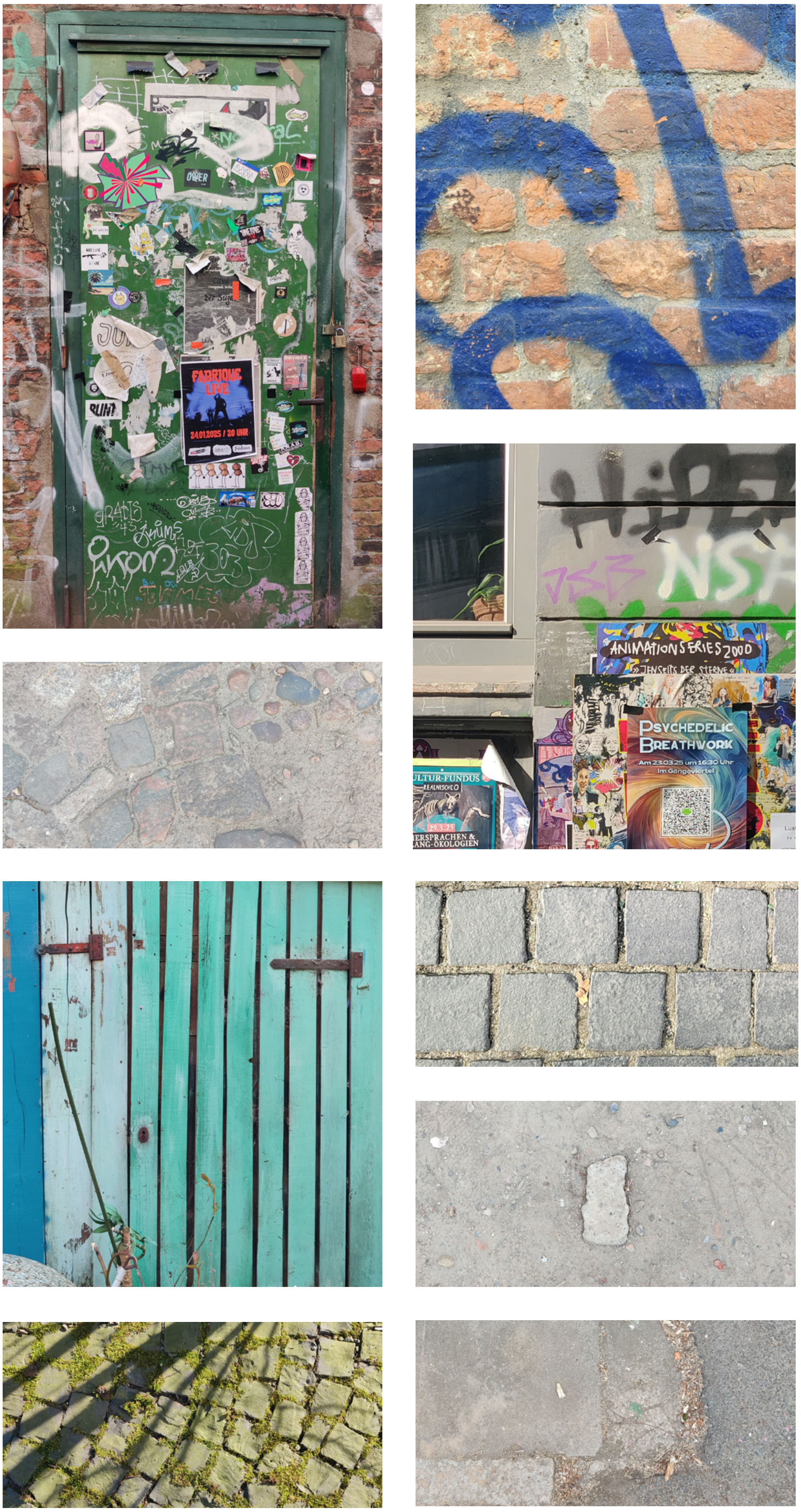
Ill. 40. Impressions of the blue and yellow route
Source: Own Image

Conclusion

The blue, green, and yellow routes especially highlight the key aspects of the Gängeviertel: informal urbanism, community-driven spaces, and adaptive design. Their contrast to the very formal and structured red route should be considered in future planning steps to achieve a more cohesive appearance, balancing diverging design languages.

Location:
Caffamacherreihe

MATERIALS

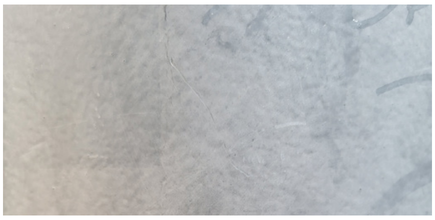


This study documents the diverse material palette found within the site. These materials will not only be used as a point of departure in the outdoor thermal comfort simulation (see Chapter Outdoor Thermal Comfort Simulation, p. 58), but they also help to identify the local character and provide insight into the historical layers of the area. The following pictures showcase a collection of materials found throughout the site, both on the ground level and on the façades of the surrounding buildings (see ill. 41–42).

Ill. 41. Material board A
Source: Own Image

Pavement

The high contrast of the site is reflected in the diversity of materials. It further highlights the area's historical layering and illustrates different phases of urban development. Correlating with the site's split between heritage preservation and contemporary urban redevelopment, which has been detailed in the chapter Gängeviertel Project and Today's Usage, p. 17, these materials have one common denominator: the lack of green or unpaved spaces. The dominant materials are traditional cobblestone (some with moss), patched and aged concrete, smooth modern paving slabs, also known as the "Hamburg Standard Pavement" (Freie und Hansestadt Hamburg, Behörde für Wirtschaft, Verkehr und Innovation, 2017), as well as asphalt and crushed aggregate surfaces.



Ill. 42. Material board B
Source: Own Image

Buildings

Graffiti, stickers, and layered paint dominate several of the surfaces in the Gängeviertel that clash with the clean, modern glass façades of the Brahmsquartier. Rusted hinges, peeling paint, and weathered textures indicate the aging and evolving character of the site and fit well into the already defined picture of the Gängeviertel, while also highlighting the stark contrast prevalent on the site.

METHODS

"In general, the integrated design process is an approach to building design that seeks to achieve high performance on a wide variety of well-defined environmental and saocial goals while staying within budgetary and scheduling constraints"

- Busby Perkins+Will & Stantec Consulting 2007: 5ff.

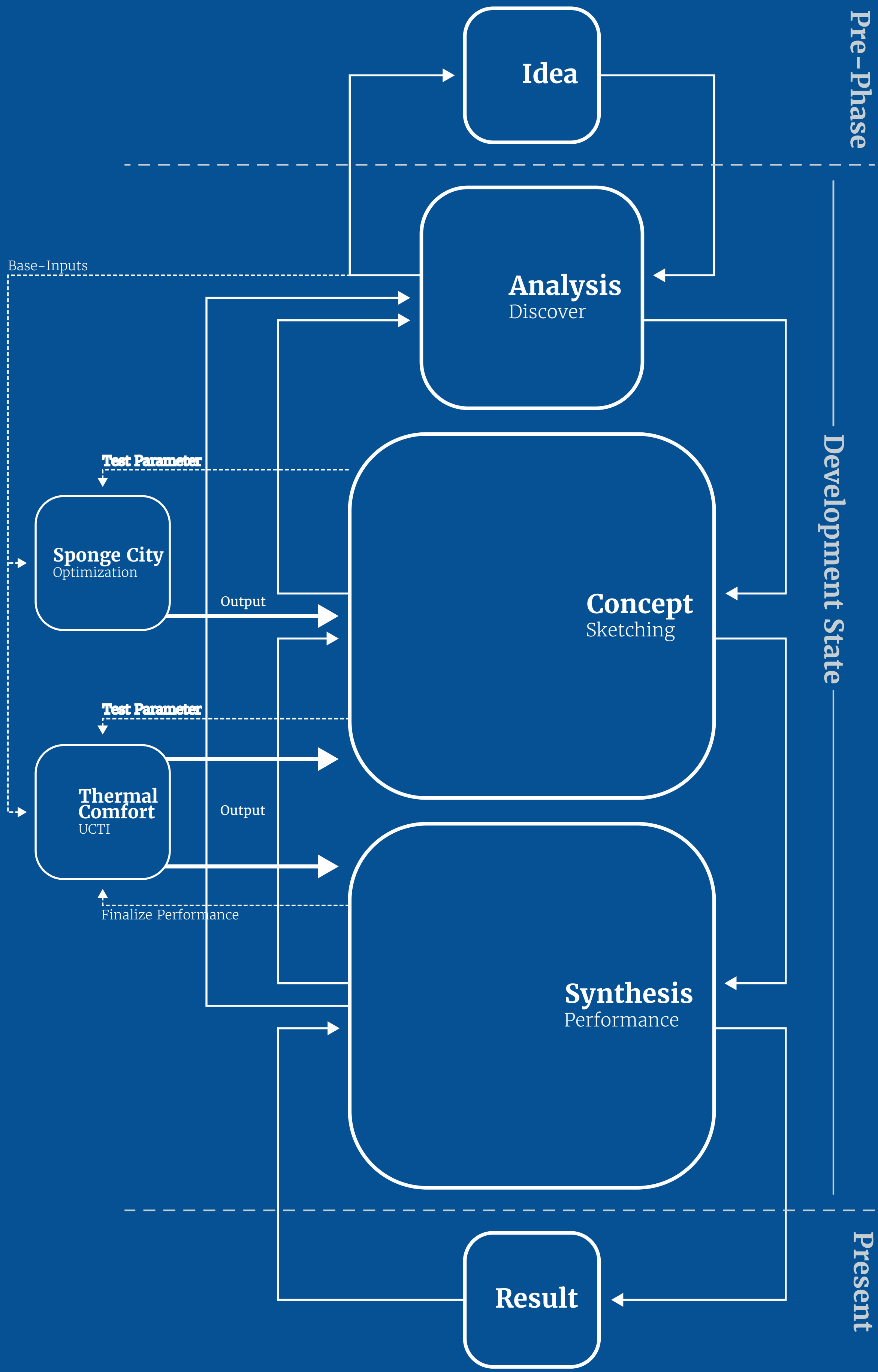
INTEGRATED DESIGN PROCESS

The Integrated Design Process (IDP) starts with pre-design preparations and concludes with the long-term operation of the finalized design. Its strengths lie in the early integration of different disciplines, a focus on goals and objectives, and an iterative workflow that allows for parameter adjustments throughout the process (Busby Perkins+Will & Stantec Consulting, 2007). As the work presented here emphasizes the integration of simulation during the early design development, a more design-centred approach to IDP, based on Knudstrup (2004), is adopted. It integrates both, sponge city optimization and microclimate simulations. In this approach, five phases detail the development of a design from its initial idea to the final presentation.

The established workflow is outlined in Ill. 43. Through an iterative process, knowledge of the site is gained from a thorough analysis of current spatial and social conditions and used to support the knowledge-based development of an exemplary design. Based on the proposed research question in the chapter Research Framework, p. 11, the finalized goal is to effectively apply sponge city principles for a decentralized rainwater management and improve thermal comfort, thereby fostering social exchange. Geyer et al., (2015) identifies simulations as effective tools to rapidly generate multiple design solutions and explore the project-specific design space. In addition, these tools can be adapted throughout the design development to further investigate emerging concepts. Simulations can help meeting defined performance standards but are also valuable for testing and quantifying concepts during the early design process.

Ladybug Tools in Grasshopper have demonstrated success in accurately predicting pedestrian thermal comfort (El-Bahrawy, 2024) and are therefore chosen for the thermal comfort evaluation. Furthermore, to optimize the implementation of sponge city principles, an approach by Xie et al. (2022) is adopted and modified to assess site-specific opportunities for effective water management. This approach has proven effective in supporting decision-making in already developed urban areas and facilitates iterations on various possible solutions. The data collected during the site analysis serves as the initial input for the simulations conducted. Further details on the setup on the simulations are provided on the following pages.

Ultimately, as part of the IDP, the simulation inputs are continuously adjusted throughout the project's development. New conceptual scenarios are tested for their hydrological performance and impact on thermal comfort, generating insights into the site-specific challenges and potential opportunities.



Ill. 43. Model workflow for an integrated design process, showing the implementation of thermal comfort simulation and sponge optimization
Source: Own Image based on Knudstrup (2024: 224)

OUTDOOR THERMAL COMFORT SIMULATION

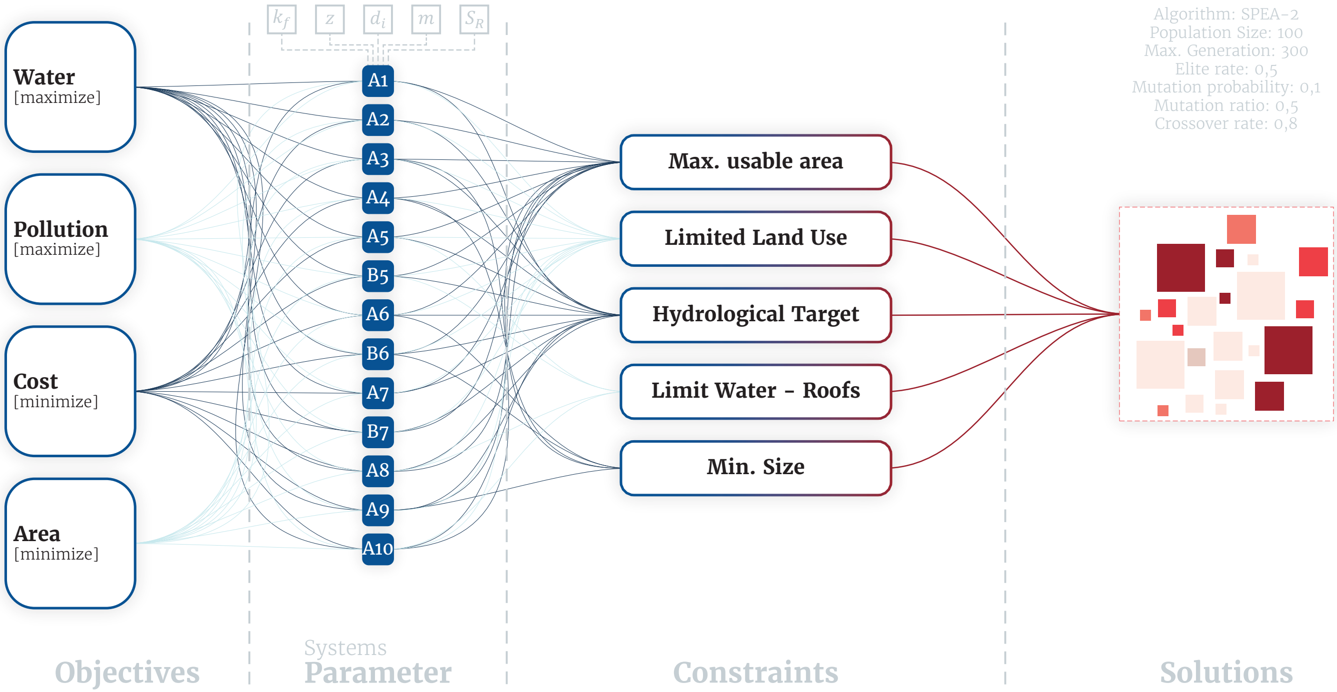
The thermal comfort and wind behaviour simulation was conducted using ©Rhino3D's Grasshopper extension in combination with the open-source plugins Ladybug, Butterfly, and Honeybee. This simulation approach is based on Mackey et al. (2017), who couple solar radiation, surface temperature, and wind data in a spatially resolved model. It has been adapted and partially simplified to accommodate hardware limitations and to reflect its relative weight within this project. As a result, the simulation days and time frames were reduced to an average cold day (December 10th) and an average hot day (June4th), each measured from 8 a.m. to 6 p.m.

Framework

In the first step, Ladybug was used to integrate weather data sourced from Ladybug Tools. (n.d.), providing initial climate data specific to Hamburg. This includes hourly temperature profiles, sun path, wind speed and direction, and outdoor comfort indices that can be converted later into UTCI, which has been defined in the chapter „Urban heat islands“ p.22. This data forms the basis of the simulation and informed the selection of relevant time frames, aligning with Mackey's proposal to correlate climate conditions with occupant behaviour in thermally diverse spaces (Mackey, 2015).

Based on this weather data, Butterfly, a Grasshopper interface for OpenFOAM, was used to simulate Computational Fluid Dynamics (CFD) and visualize wind flow across the site. This was done within a predefined radius and level of detail after meshing the geometry and assigning boundary conditions, including buildings and site topography, which were simplified to enhance simulation speed. The approach follows the methodology outlined in the IBPSA 2017 paper, aiming to identify wind accelerations and flow directions (Mackey, C et al. 2017)

Utilizing the weather file data in combination with Butterfly's wind speed and direction outputs, Honeybee was then used to calculate surface temperatures and ground heat absorption via the integrated EnergyPlus simulation engine. This allowed for the assignment of specific materials to different areas of the model. These materials correspond to those identified in the chapter Materials, p. 54f., and include properties such as thickness, conductivity, density, specific heat, roughness, thermal absorption, solar absorption, and visible wavelength absorption (see appendix B.2 for details). The resulting output will be discussed in chapter Results, p.62, showing UTCI temperatures across the site overlaid with primary wind flow directions and speeds.



Ill. 44. Model workflow for the sponge city multi-objective optimization
Source: Own Image based on Xie et al. (2022: 3294)

SPONGE CITY-OPTIMIZATION

The simulation tool used here was initially developed by Xie et al. (2022) to help designers create effective solutions when combining different technologies of rainwater-management systems. It returns a combination of rainwater-management systems and their respective size (in m²), that may be established to meet performance goals for a sponge city development.

The tool runs in Grasshopper, based in ©Rhino3D. It utilizes the Octopus plug-in, which was developed by the University of Applied Arts in Vienna, Austria, and Bollinger+Grohmann Engineers. This plug-in allows its user to optimize a scenario based on pre-determined objectives (multi-objective optimization) and can deliver numerous possible solutions. In general, the Strength Pareto Evolutionary Algorithm-2 (SPEA-2) is used to minimize an objectives value as much as possible. The results are used as a starting reference for designers to discuss and eventually meet the set hydrological goals for a successful Sponge city concept. Finally, the designer must still be mindful about the simulation and may deviate from its results (Xie et al., 2022).

Model Framework

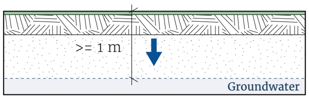
The model presented consists of three phases for inputs to be made (see ill. 44). As suggested by Xie et al. (2022), design objective functions must specifically be chosen depending on a project's goals and performance targets.

Next, possible rainwater-management systems are chosen and established as decision variables for the simulation to solve for (see Ill. 45). The list used here is not representative of all existing systems and technological variants, but presents a generalization based on DWA (2005), DWA (2013) and Pfoser & Jenner (2014) (see appendix C.3 for more details). The ultimate decision variables represent the horizontal area used in m². They consist of adjustable parameters, specific to the rainwater facility, such as maximum water depth and slope gradient.

Eventually, constraints are put in place to filter out unfavourable solutions produced by the algorithm. These can vary depending on the site and local regulations but improve performance of the algorithm and reliability of the results (Xie et al., 2022).

Lastly, the SPEA-2 solves based on inputs to generate possible combinations of sponge facilities. Thereby, thousands of scenarios, with different characteristics (e.g cost-effectiveness) are created and open for evaluation by the architect. For more details, refer to Xie et al. (2022).

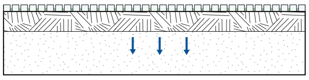
Grass Strip – A1



Based on DWA (2005: 24)

Water is being infiltrated on open, unpaved soil. Usually, grass is planted for vegetation. The surface area needed is very large, however a layer of organic soil leads with at least 10cm of thickness, serves as a good pollutant control (DWA, 2005).

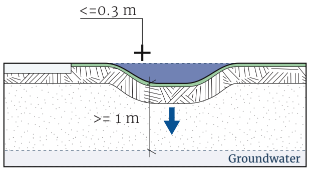
Permeable Pavement – A2



Based on DWA (2005: 24)

On a legal level, permeable pavements don't qualify as infiltration systems. However, they allow water to infiltrate, while providing structural support for heavy loads (DWA, 2005). Over time, their performance can lower drastically (Borgwardt, 2006).

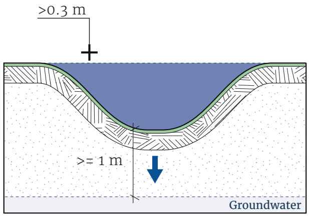
Grass Swale – A3



Based on DWA (2005: 25)

This system combines infiltration with a small storage space. Water levels of up to 30 cm are recommended, enhancing performance. A layer of organic soil cleans polluted runoff (DWA, 2005).

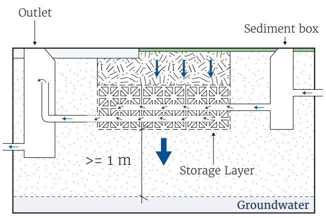
Infiltration Basin – A4



Based on DWA (2005: 28)

Construction-wise, infiltration basins are similar to grass swales. Even so, they are constructed with higher water-levels, storing more water with less space required. The higher amounts of water also put more pressure on its ability to remove pollutants (DWA, 2005).

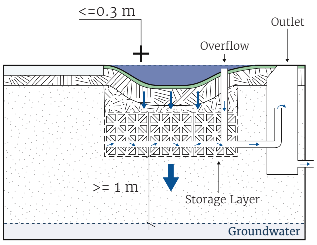
Infiltration Chamber – A5/B5



Based on DWA (2005: 26)

Storage modules are placed underground, receiving water through pipes, or a surface opening with filling material. There, water is stored and infiltrated. While surface space is preserved, the water doesn't pass the organic soil layer, potentially polluting groundwater. For badly infiltrating soil, a controlled discharge can be added (DWA, 2005).

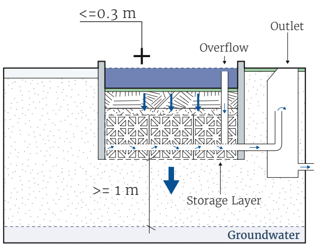
Infiltration Trench – A6/B6



Based on DWA (2005: 25, 28)

Combining a grass swale and an infiltration chamber, this system provides surface and subsurface storage. The water arrives in the surface depression, where it infiltrates into the storage modules. Passage through an organic soil-layer provides good pollutant removal. A controlled discharge can be added (DWA, 2005).

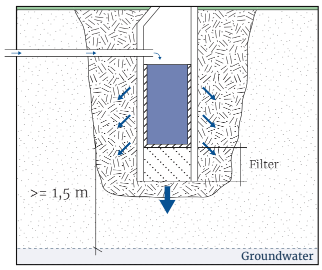
Rain Garden – A7/B7



Based on DWA (2005: 25, 28)
& SenUVK (2018: 22f.)

Constructed similar to an infiltration trench, the surface storage capacity is increased by using a concrete holder, instead of a naturally shaped depression. The garden area is positioned at the bottom of the pool. This system is used when there is very little space available, as costs are high (SenUVK, 2018; DWA, 2005).

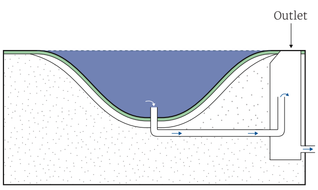
Infiltration Pit – A8



Based on DWA (2005: 27)

Infiltration pits are circular shaped shafts in the ground. Technically, its depth is only limited by the distance to the groundwater. Even though it utilizes filter-layers, the water doesn't pass through an organic soil-layer, leading to almost no removal of pollutants (DWA, 2005).

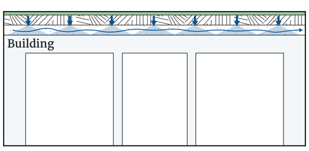
Rain Basin – A9



Based on information from DWA (2013)

This system is constructed to store water, slowly releasing it to the sewage system or following systems. As water is not supposed to infiltrate, a sealed layer is required. In general, this system is not designed to remove pollutants, though sedimentation of particles can occur (DWA, 2013).

Green Roof – A10



Based on Pfoser & Jenner (2014: 72f.)

Vegetation is introduced to building roofs, with a substrate layer being the base for any vegetation. With increasing thickness of the substrate, higher amounts of water can be stored. However, its implementation is limited by the building's static, and the angle of the roof should be lower than 10 ° (Pfoser & Jenner, 2014).

Ill. 45. Selected rainwater-management systems, used for the simulation
Source: Own Image

Objectives

As mentioned before, objectives are instructions for the multi-objective-algorithm to solve and optimize for. These set a base reference for possible results and must be chosen in accordance with the project's goals. While all objectives stand alone, they holistically affect each other. For this project, objectives for sponge city principles are chosen (Xie et al. 2022). Additionally, as there are land use conflicts in dense developed urban areas (Haaland & van den Bosch, 2015), a fourth objective, to reduce the used area, is introduced. Details on calculations and use parameters are shown in appendix A. The specific objectives are as follows:

(1) Water (maximize)

The total amount of water stored, infiltrated and discharged is calculated for each individual rainwater facility and the results summed up for a total hydrological objective value. The calculations are based on a rain-duration of 120min for a 5-year rain-event, leading to a hydrological performance value for each facility. As the algorithm introduced in Grasshopper seeks to minimize its objectives, the hydrological performance is multiplied with -1 to maximize (see appendix C.4 for formulas).

(2) Pollution (maximize)

The DWA (2005: 14) classifies infiltration systems into 5 categories according to their ability to remove pollutants effectively. This is used as a starting point to classify additional rainwater facilities and derive a pollution score (1-5). The pollution score is set in relation to the overall area a facility handles, and all inputs summed up as the objective value. The result is multiplied with -1 to maximize (see appendix C.5 for formulas and scores).

(3) Cost (minimize)

There are severe financial hurdles when implementing sponge city concepts (Nguyen et al. 2019). To estimate potential cost for a Sponge city concept and minimize the financial investment, prices for different rainwater facilities are collected (see appendix C.6 for formulas and prices).

(4) Area (minimize)

As densification and conflicts for land use become a struggle in cities (Haaland & van den Bosch 2015), space for rainwater-management is scarce and must be preserved as much as possible. The simulation was designed to minimize the land required for rainwater-management, by summing up all decision variables and using the combined sum (total horizontal area in m^2) as an objective to minimize.

Constraints

The study from Xie et al. (2022) has shown that using constraints improves the reliability of calculated scenarios and the speed of the algorithm. The imposed constraints are based on the mentioned study and technical guidelines specific for Germany. They are as follows:

(1) Maximum usable area

Based on the calculated land use limitations for each sponge city facility, a maximum usable area (in m^2) for sponge city programming is determined.

(2) Limited Land Use

For each individual rainwater facility, there exist physical limits to its optimal usage (e.g. soil infiltration rate). Based on this, the maximum aerial extend for each facility is calculated and used as a limiter for the decision variables in the simulation (see chapter Spatial Limitations, p. 64f., for details).

(3) Hydrological Target

While rainwater facilities are commonly calculated using an approximation method for several rain-durations (DWA, 2005; DWA, 2006), the proposed simulation needs a specific target value to check for. Based on the hydrological calculations for several rain-events, roughly 50% of precipitation occurs during the first two hours (see chapter Hydrological Analysis, p. 38f.). Additionally, DWA (2005; 2006) suggest designing for a 5- or 10-year rain-event. Eventually, a 5-year rain-event with a duration of 120min is chosen for this project. An additional 10% in performance is chosen to create more variety in solutions.

(4) Limit Water – roofs

The rainwater facilities A5, B6 and A8 are unable to properly remove pollutants from rainwater, which may endanger groundwater. Its use case is restricted by authorities to only receive lightly polluted runoff from roofs (DWA, 2005). Additionally, A10 (green roofs) can only receive rainwater falling on roofs. In the simulation, the combined hydrological performance for these facilities was restricted to the water received on roofs.

(5) Minimum Size

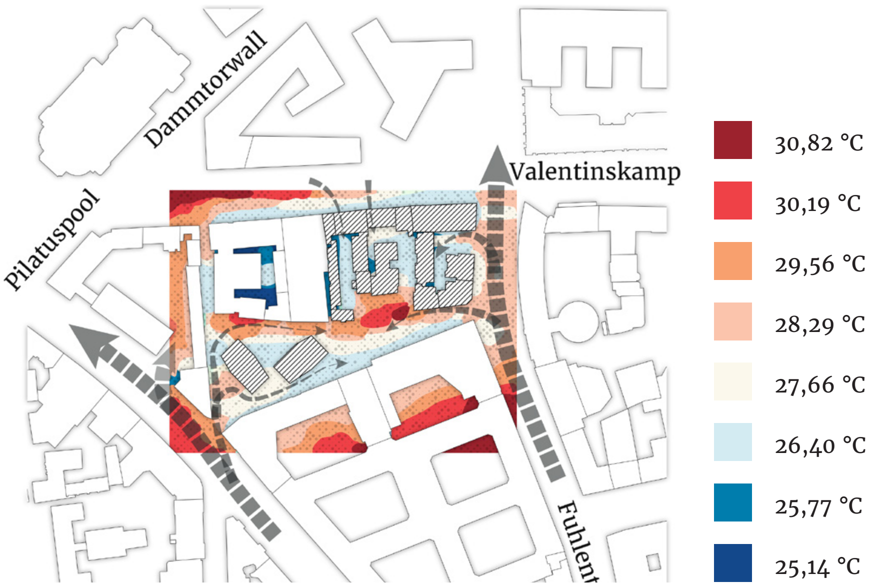
The rainwater facilities A3, A4, A6, B6 and A9 may be designed using a sloped pond. This slope can be pre-determined in the simulation but requires a minimum area to be able to reach the specified target depth. In the simulation, the rainwater facilities are calculated as a truncated pyramid and based on this, the possible minimum size (in m^2) calculated for a set target depth.

Mathematical expressions and chosen values are shown in appendix C.7.

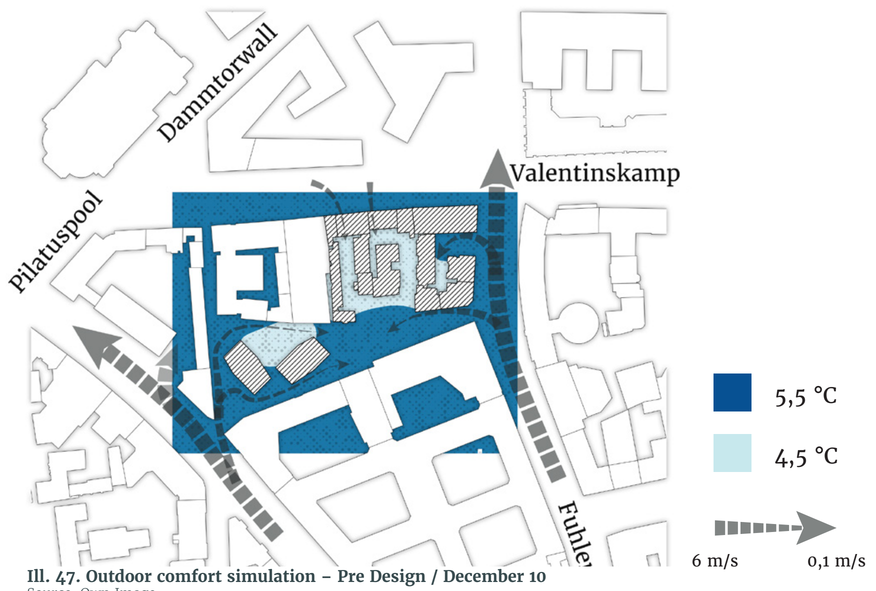
RESULTS

OUTDOOR THERMAL COMFORT SIMULATION

The following chapters will detail the work that has been done to produce the simulations and further specify the limitations and constraints that were applied, aswell as discuss the obtained results.



Ill. 46. Outdoor comfort simulation – Pre Design / June 04
Source: Own Image
Dataset: See Ill. 49



Ill. 47. Outdoor comfort simulation – Pre Design / December 10
Source: Own Image
Dataset: See Ill. 49

Baseline Simulation
The initial simulation is used to assess the current situation in the area and identify hotspots that need intervention. The materials used in the different parts of the site are in appendix E (Ill. 1) and consist of soil, grass, cobblestone, concrete tiles, and asphalt. These are the materials that have been documented in the chapter, Materials, p.54f. Their specific material characteristics can be seen in appendix B.2.

As illustrated in ill. 46, the highest temperature in the area is measured in the centre of the district. Here, a maximum temperature of 30.82°C is reached for the 4th of June. Overall, the highest temperatures can be seen along the Speckstraße and the open space in front of the Gängeviertel. Comparably, the temperatures along the office building at Brahmsquartier and inside the narrow pathways at Gängeviertel are lower. The differences can be explained with the wind entering the site with similar intensity from east and west, resulting in lower wind speeds at the centre of the site and reducing the cooling effect. Additionally, the findings from the shadow study in chapter Shadows, p.36, suggest lower temperatures in areas with shading from buildings. However, the outdoor comfort for the 10th of December shows average calculated temperature of 4.5°C in the open spaces of the area and 1°C warmer in the more protected spaces of the Gängeviertel (see ill. 47).

Second Simulation: Targeted Mitigation in Heat-Stressed Areas

Using the results of the first simulation and factoring in the design principles shown in chapter Design Principles, p. 69., interventions were made to utilize Sponge City principles as a solution for issues to thermal comfort. The interventions paid particular attention to the central space in front of the fabrique building and along the Speckstraße.

Design Strategy

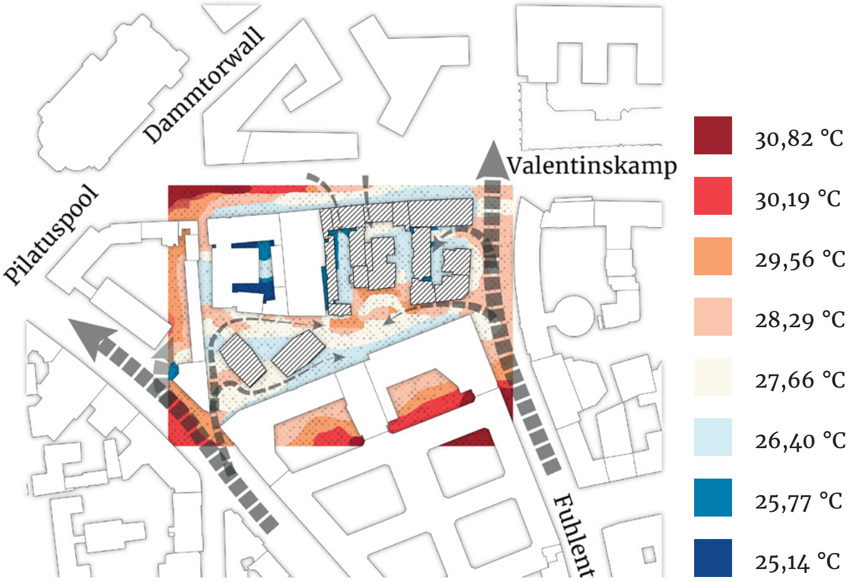
While the first simulation revealed that the cobblestone surface contributed to elevated surface temperatures in certain locations, it also highlighted that other areas, like directly along the office building in the Brahmsquartier, are affected less severely. Therefore, as part of the design, cobblestone surfaces were only removed in the areas with particularly high surface temperatures, and the existing pavement was retained in the other areas, contributing to the sustainability and budgetary efficiency of the project.

Surface Treatments and Material Changes

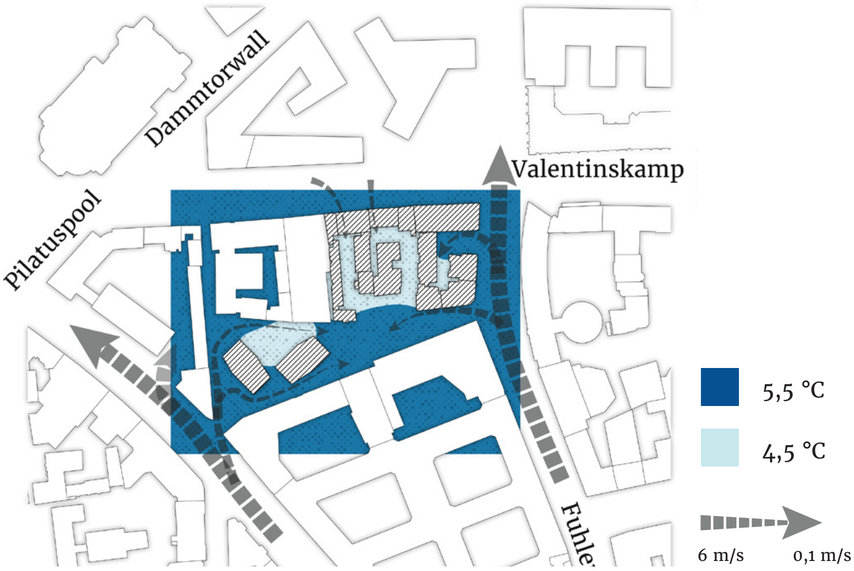
Where possible, an increase of vegetation throughout the design has been planned, supporting evaporative cooling and increased surface shade, as discussed in Chapter Thermal comfort, p.26. In the areas of elevated heat, a cooling pavement (see appendix B.2) has been selected for its improved performance compared to conventional cobblestone. However, many of these areas had previously been simulated with a soil surface, which, due to its specific properties (see appendix B.2), already performs well in mitigating heat. As such, replacing it with a thermally improved cool pavement only results in marginal overall improvements to surface temperature in the areas previously covered by soil. Lastly, while water is introduced to the project site, it is not meant to be store over extended periods of time and therefore not considered as a cooling factor.

Results

While a small reduction in surface temperature, especially in the hottest areas, can be observed, the overall impact of the intervention is relatively modest, with a temperature reduction of about 1–3°C. Most notably, the maximum temperatures of the open space at Gängeviertel have been reduced, better connecting the north and the south thermally.



Ill. 48. Outdoor comfort simulation – Post Design / June 04
Source: Own Image
Dataset: See Ill. 49



Ill. 49. Outdoor comfort simulation – Post Design / December 10
Source: Own Image
Datasets:
Buildings – Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads – Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

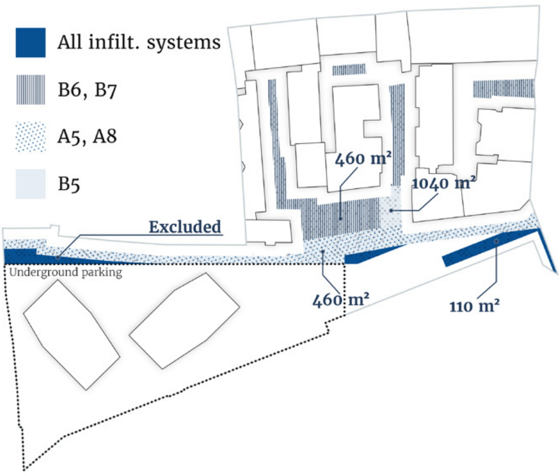
SPONGE CITY-OPTIMIZATION

Spatial Limitations

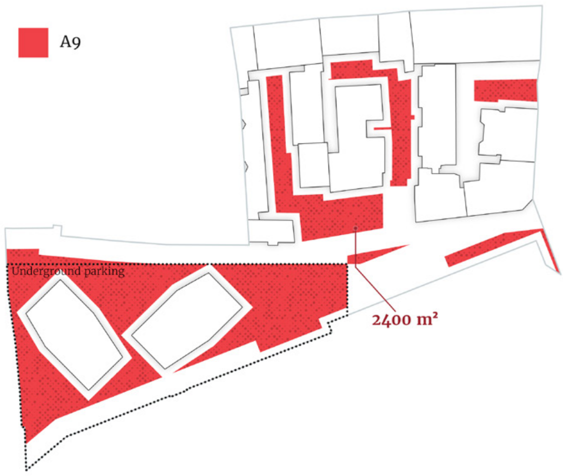
Specific physical and regulatory constraints are in place, that limit the use of rainwater-management systems over others. For details on the used rainwater-management systems, refer to chapter Methods, p. 60. On the one hand, the spatial limitations served as a numerical constraint for the maximum possible surface area that the different rainwater-management systems could occupy, on the other hand, they were used as strategic design guidance for the possible placement and dimensioning of rainwater systems (see Ill. 50-53). To investigate the possible usage of infiltration systems, DWA (2005) suggests considering the:

1. Infiltration rate (kf) and homogeneity of the existing soil
2. Distance to groundwater and direction of flow
3. Topography
4. Soil pollution
5. Water protection areas

Details in chapter Hydrological Analysis, p. 38f., and Soil Analysis, p. 40

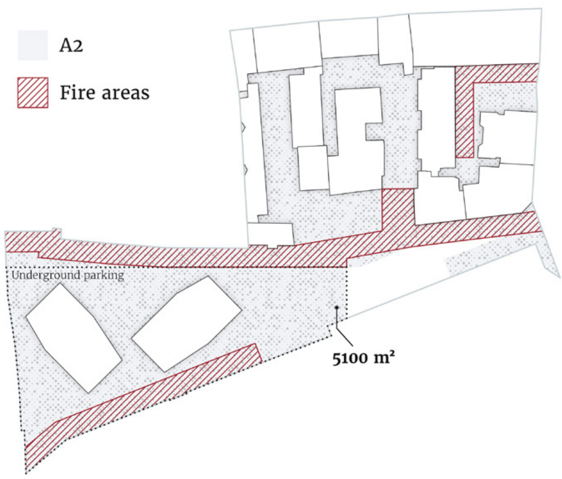


Ill. 50. Spatial limitations for Infiltration Systems, 1:2000 – A1/A3/A4/A5/B5/A6/B6/A7/B7/A8
Source: Own Image
Dataset: See Ill. 53



Ill. 51. Spatial limitations for Rain Basins – A9
Source: Own Image
Dataset: See Ill. 53

Ill. 52. Spatial limitations for Green Roofs, 1:2000 – A10
Source: Own Image
Dataset: See Ill. 53



Ill. 53. Spatial limitations for Permeable Pavements, 1:2000 – A2
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)

The distance to groundwater is high at 8,2m, not limiting any infiltration. Moreover, there is no evidence of soil pollution and no water protection area implemented for the site. However, while the infiltration rates are good according to public data, talks with a local revealed difficult soil conditions for the historical area of the Gängeviertel (see appendix A). This limits infiltration to using systems with additional drainage. The topography also suggests limited use of surface infiltration in the western part of the site, as water naturally collects in the eastern part.

Additionally, to prevent damage to buildings and water inundation into basements, infiltration systems should be constructed at a clearance of at least 1,5 times of the buildings sole depth. Though, this only applies to buildings that are not constructed watertight (DWA, 2005). See appendix C.7 (table 7) for a visual representation. For this purpose, the southern building of Brahmsquartier was assumed to be watertight, due to its deep underground garage, while the sole depth of Gängeviertel was assumed to be at 2m below the surface. In general, a distance of at least 2m to all buildings was chosen as a minimum for all systems to ensure enough space for technical solutions, if needed.

Lastly, the information mentioned above don't apply to A2 – Permeable Pavements, as they are not referred to as infiltration systems in a legal sense. However, sufficient paved area must be available for fire trucks, making permeable pavements useable here. Fire trucks are required to have 5,5m of clearance to operate (Freie Hansestadt Hamburg, 2009). Another option here are subsurface systems, like A5 – Infiltration Chambers. Also, A10 – Green Roofs are limited to roofs at an angle lower than 10° and the statics of a building must be checked to withstand the additional weight (Pfoser & Jenner, 2014).

Result-Matrix

The simulation returned 53.691 valid results, based on the set objectives, parameters and constraints presented in the chapter Sponge City Optimization, p. 59ff. The results represent a combination of different rainwater management systems with a related numerical value for the suggested spatial extend. All scenarios offer differences respective to the set objectives (Pollutant removal, Cost-effectiveness and Area-effectiveness). As a baseline, all scenarios had to meet the hydrological performance standards to be valid. Ultimately, the different calculated scenarios serve as guidance for the spatial possibilities a site offers regarding rainwater management

	Average	Average	Average	Cost-Efficient	Pollutant-Efficient	Area-Efficient
Hydrological Performance [m³]	206	222	206	206	206	206
Pollutant Removal	0,563	0,652	0,526	0,388	0,695	0,666
Cost-Effectiveness [€]	125.000	162.000	109.000	98.000	173.000	170.000
Area [m²]	750	751	819	444	786	235
A1 Grass Strip	0	0	0	0	0	0
A2 Permeable Pavement	0	0	0	0	35	0
A3 Grass Swale	0	0	0	0	0	0
A4 Infiltration Basin	38	39	38	38	39	37
A5 Infiltration Chamber	0	0	0	0	0	0
B5 Infiltration Chamber (Discharge)	0	0	0	0	0	0
A6 Infiltration Trench	69	68	75	46	68	66
B6 Infiltration Trench (Discharge)	35	112	0	0	106	132
A7 Rain Garden	0	0	0	0	0	0
B7 Rain Garden (Discharge)	0	0	0	0	0	0
A8 Infiltration Pit	0	0	0	0	0	0
A9 Rain Basin	116	41	145	198	0	0
A10 Green Roof	492	491	561	153	520	0

Ill. 54. Result from the multi-objective optimization for the spatial extend of numerous rainwater-management systems [in m²]
Source: Own Image

Out of the pool of valid scenarios, three average scenarios were taken into consideration for further design investigation, with the first one shown ultimately creating the base for the design proposal. Additionally, three scenarios most suitable for one respective objective are shown as a reference. Though the numerical spatial extents differ between the simulated scenarios, the presented results in general suggest a combination of A4 – Infiltration Basin, A6 – Infiltration Trench, B6 – Infiltration Trench with discharge, A9 – Rain Basin and A10 – Green Roof (see ill. 54). It must be said that, due to the high number of calculated scenarios, the ultimate choice of the respective scenario is made by the designer and their goals in mind.

SUMMARY OF INSIGHTS

This summary aims to compile the findings of the chapter Theoretical Background, p. 20, Site Context and Analysis, p. 32 and Methods, p. 56, and give an overview of findings for the Design proposal in the following chapter.

The focus of this thesis is to rethink urban design and showcase how Sponge City principles and microclimate simulations can be meaningfully integrated into the early stages of a design. Starting with the choice of the site, the Gängeviertel and Brahmsquartier was intentional, a site shaped by grassroots activism and with ongoing tension between old and new. The site offers a testbed to demonstrate how climate-resilient design can be integrated in small urban spaces, while supporting social activities. However, for a final proposal, many steps had to be considered:

Theory
Based on the theory, 3 main pillars are derived for the subsequent design proposal and workflow established (see chapter Theoretical Background, p.20):

1. **Sponge city principles**
Managing stormwater locally through nature-based solutions by using concepts like permeable pavements, green roofs, and local water retention enhances climate-resilience and reduces hydraulic stress on sewage systems. As a side-effect, additional vegetation and water is introduced to a local site. However, site-specific physical limitations, budget constraints, legal limits and the wishes of actors must be taken into consideration.

2. **Urban Heat mitigation**
Surface materials, vegetation, water bodies, and geometry can have a severe impact on a local climate. As high temperatures negatively affect pedestrian comfort and their perception of space, factors like shading, evapotranspiration from vegetation, ventilation and material properties can be adjusted to improve thermal accessibility.

3. **Performance-based design thinking**
Including environmental performance into the early design stages to make designing more calculated, knowledge-based, and efficient. It is meant as a tool to support decision-making, enhancing the architect's judgement and helps in investigating the designated design space more quickly.

Following these theories offered a substantial framework on how Sponge City principles and pedestrian outdoor comfort show synergies and can be utilized as part of a holistic, climate-adapted urban design. As such, possible design tools and interventions were recognized and evaluated using a performance-based approach.

Analytical Foundation
Sheltered from its surroundings, the heavily pedestrian-frequented area is already well visited, but people tend to leave, rather than stay. The southern area at Brahmsquartier is thereby used to cross the site. In part, this is certainly due to the lack of activity in the space and splitting of the site by the privately owned Speckstraße. It runs across the site, giving access for emergency vehicles, but also resulting in a fragmented urban space. A walk through the site unveiled the contrast of a layered quarter, shaped by a rich history and a strictly modern, minimalistic counterpart.

As part of implementing Sponge City principles, the project site is highly limited by a lack of space, but its conditions of the underground. The two-story underground parking, in combination with partially restricted soil infiltration and complex topography, make water management difficult. Despite this, good thermal conditions are for the most part provided in shaded areas, with specific attention to be paid on the central open space.

Together, these factors informed the need for targeted interventions that could address water management, thermal comfort, and spatial cohesion for a better-connected environment.

Methodological Integration
Two simulations were conducted and integrated into the well-tested Integrated Design Process (IDP). These include (see chapter Methods, p.56):

1. Outdoor Thermal Comfort Simulations to identify zones of different thermal comfort
2. Sponge City Optimization to identify possible solutions for integrating rainwater-management systems

The results of these simulations actively guided the design process and ultimately, the outdoor thermal comfort simulation was used to evaluate the new design's thermal performance.

Ill. 55. Central plaza and fabrique building at Gängeviertel
Source: Own Image

From knowledge to design

Now that the multi layered understanding of the site, grounded in climate data, spatial logic and ecological theory has been set, this knowledge can be applied to produce a prototype that brings mere ideas to life. Starting with the project's vision for the site, the following chapters will detail the design concept and end with the sponge city toolbox, offering guidance for other projects aiming to improve urban resilience.

DESIGN PROPOSAL

VISION

The design proposal envisions to transform the internally disconnected Gängeviertel and Brahmsquartier into a single, cohesive, climate resilient and human scaled urban space. By optimizing the implementation of Sponge city principles and using microclimate simulations during the early design stages, this project aims to balance the rich history of the site with future oriented ecological performance. Multifunctional greenspaces should aid in creating thermally comfortable space by replacing underutilized, sealed and oversized open areas, as well as reduce the dominance of large-scale structures. A realignment of the central main plaza towards the culturally engaging Gängeviertel further aims to allow the site to live up to its position as a vibrant node, increasing not only walkability but also social interaction.

This project further destines to showcase how sponge city principles can be applied on a small scale in urban areas, allowing Hamburg‘s broader green network to be expanded in smaller interventions. Eventually, the project aims to contribute to a liveable, environmentally responsive and socially just future.

DESIGN PRINCIPLES

Strengthen the connection between Brahmsquartier and Gängeviertel
Create a unified and intentional public space by designing a cohesive layout that fosters interaction between the two areas and mitigates the visual and physical barrier of Speckstraße.

Implement sponge city principles
Reduce pressure on the existing water infrastructure by incorporating Low Impact Development (LID) tools within the design, enabling decentralized rainwater management.

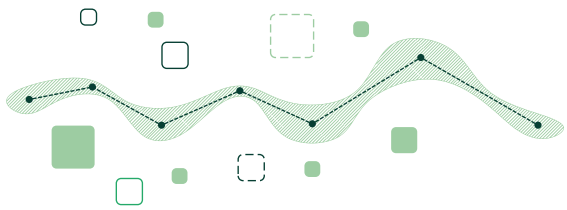
Rethink play elements
Encourage play and social interaction by making play elements an integrated part of the design rather than standalone features.

Design flexible spaces
Design places that serve multiple purposes to maximize space efficiency and accommodate the changing needs of the site.

Increase the impact of the Gängeviertel on the whole project site
Increase the attractiveness and character of the site by setting the fabrique building as the focal point of the main plaza, both visually and experiential.

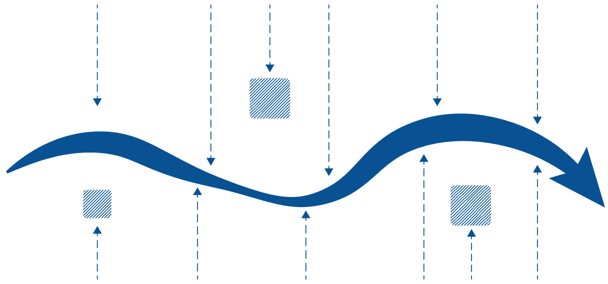
Improve thermal comfort
Improve the user experience in heat events using cooling materials and diverse vegetation.

KONZEPT



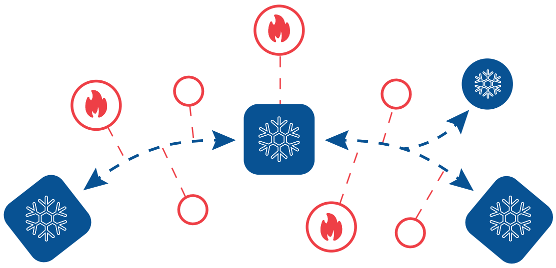
Ill. 56. Green thread
Source: Own Image

A **Green Thread** connects the site and acts as a visual axis



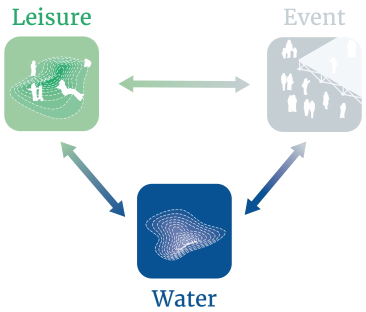
Ill. 57. Central flow of water
Source: Own Image

The idea of a **Central Flow** mimics a river-like environment for managing water



Ill. 58. Thermally connected space
Source: Own Image

A **Thermally Connected** environment creates a continuous comfortable space for people to access

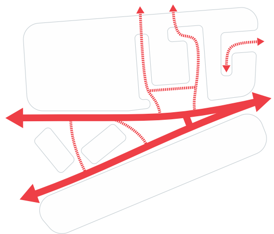


Ill. 59. The idea of multifunctional design
Source: Own Image

Multifunctional Design activates space for purposes outside of water-management

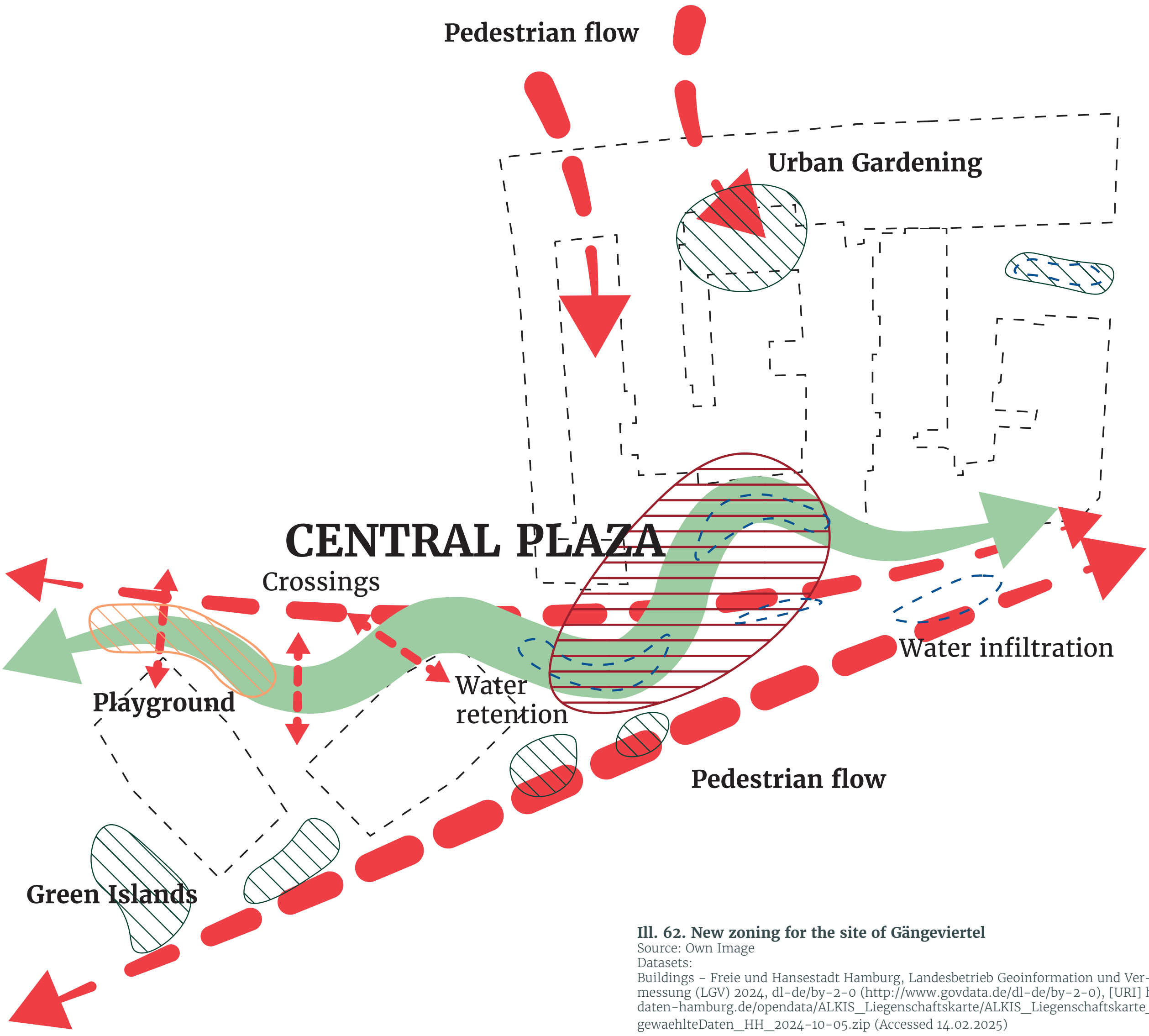
Ill. 60. Linking old with new pavement
Source: Own Image

Linking Pavements to utilize properties of different materials for zoning and improvements to thermal comfort



Ill. 61. Adaptation of familiar wayfinding
Source: Own Image

Familiar Wayfinding to make use of existing, historically developed routes



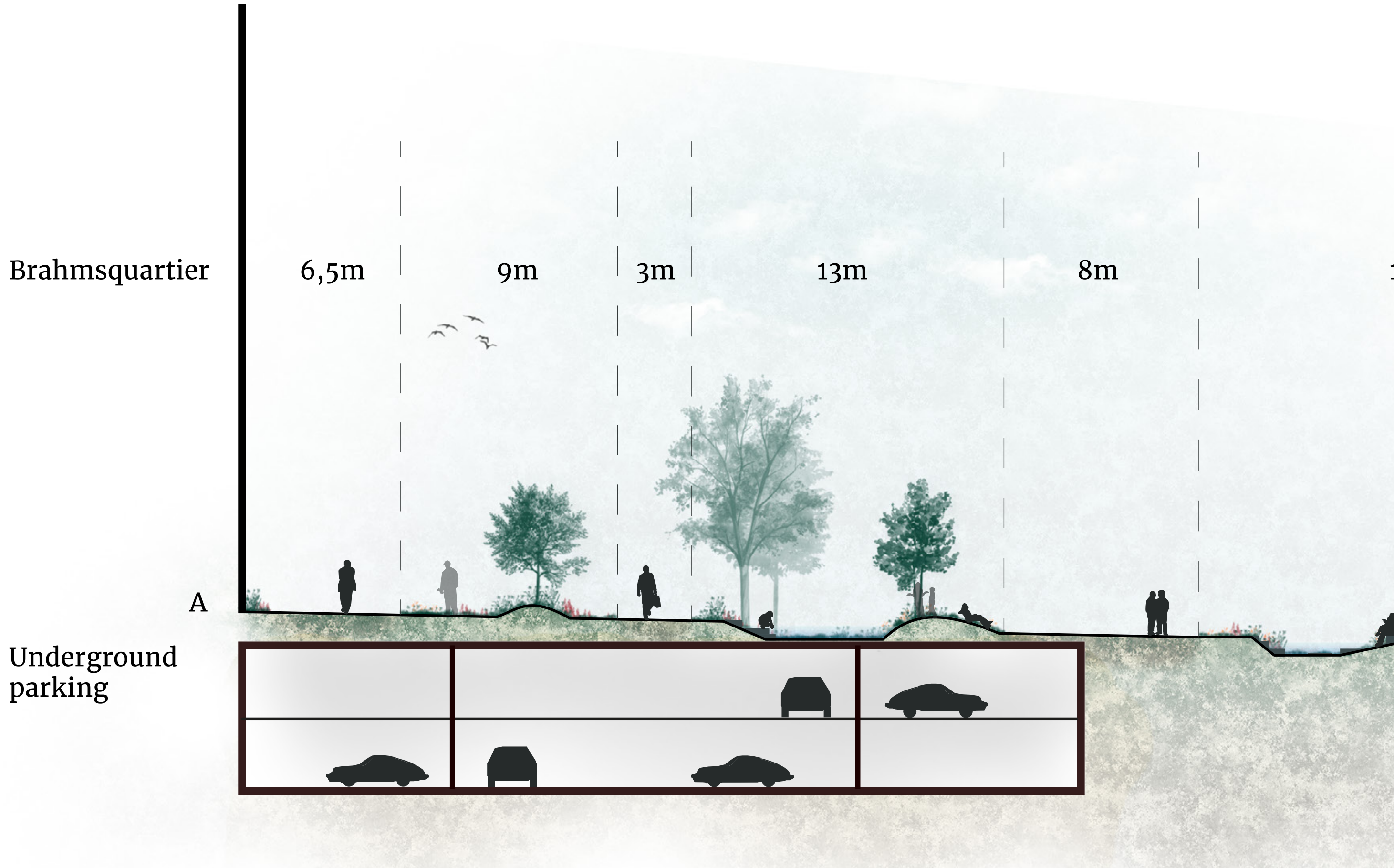
Ill. 62. New zoning for the site of Gängeviertel
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (LGV) 2024, dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)

ZONING

For the newly developed design, the space has been remodelled, while supporting existing programming and sustaining wayfinding. The historical part of Gängeviertel features minimal design intervention to give space for the diverse cultural programming. The backbone of the design is the meandering natural green connection, visually connecting the part of the historical Gängeviertel to the Brahmsquartier and the project's site centre. Smaller green islands soften the sharp built environment and shape smaller spaces that invite to stay.

At the same time, the green thread supports the hydrological management at the site. Based on the results from the chapter Sponge City Optimization, p. 64f., a connected central water-management is established. Two rain basins with a capacity of 45m³ are connected for storage space, with the later slowly discharging into an infiltration basin able to store 40m³ of water. From there, water can infiltrate or be discharged into the sewage system in emergencies. The concept is accompanied by infiltration trenches, lowering the total load on the central stream, while offering multifunctional usage during a dry period. A final assessment of the design can be found in appendix D.

SECTION



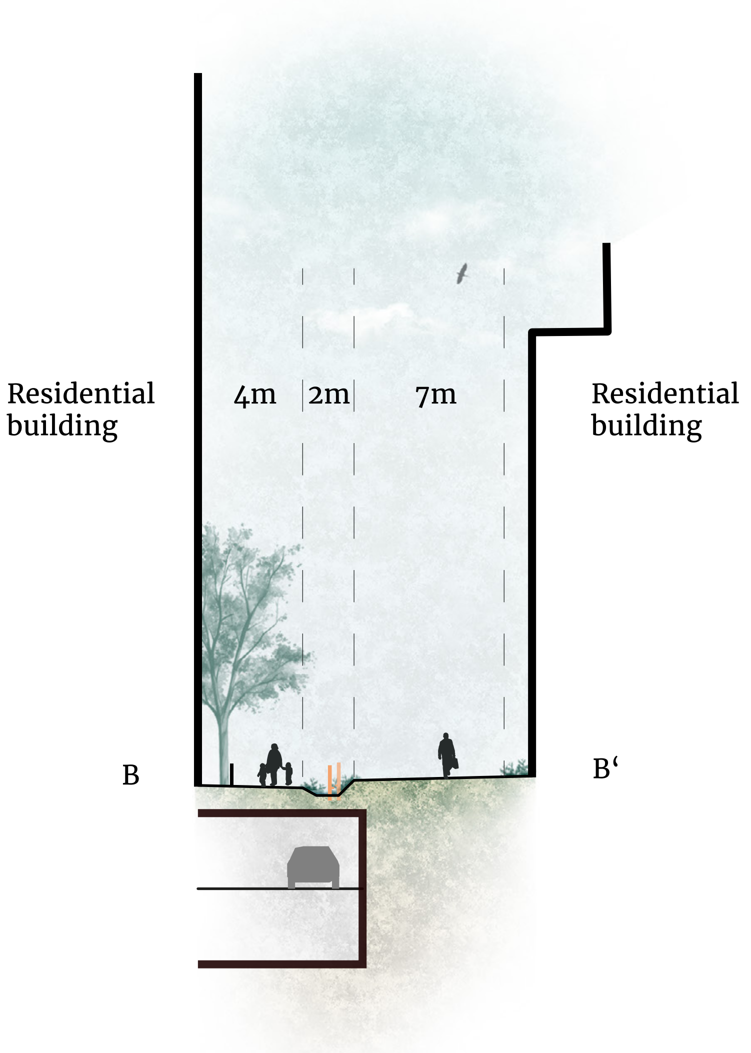
Ill. 63. Section A-A' - Design
Source: Own Image

Section A-A'

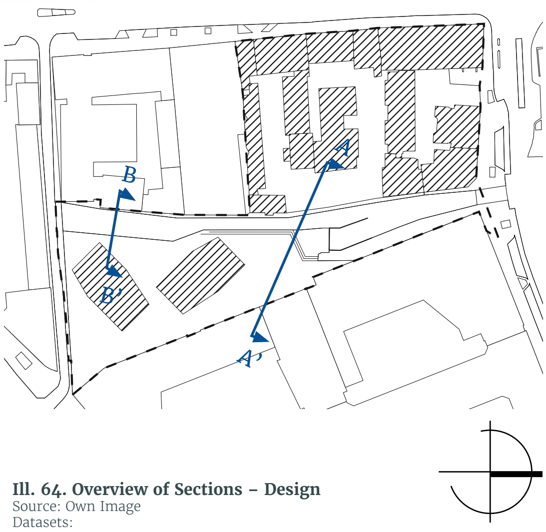
Section A depicts the topography that gives the central area of the site its character. While the area is generally dropping from west to east, it is also sloping from south to north to allow the water, allowing water to flow from one retention basin into the other as a connected system. Besides the purpose of the basins to hold back water, they serve several additional purposes. Inside the basin, several steppingstones, situated on different levels in between varying vegetation, create intimate spaces for the users in the area. Bridging the height gap between the Brahmsquartier and the Gängeviertel, a hill marks the end of the southern basin and simultaneously allows for visitors to lay, sit and be entertained in regularly held events at the Gängeviertel.

Section B-B’

Section B illustrates a narrow section of the meandering retention river. Highlighted here is the jump in heights given through the existing conditions of the site from north to south, resulting in a steeper drop towards the residential building in the south. Similar to the basins shown in Section A, the river also has a multifunctional design. Here, play elements for children allow to play along the green spine even while the basin holds low levels of water. Stepping trunks can be used along a bigger play path to cross the river on multiple occasions.



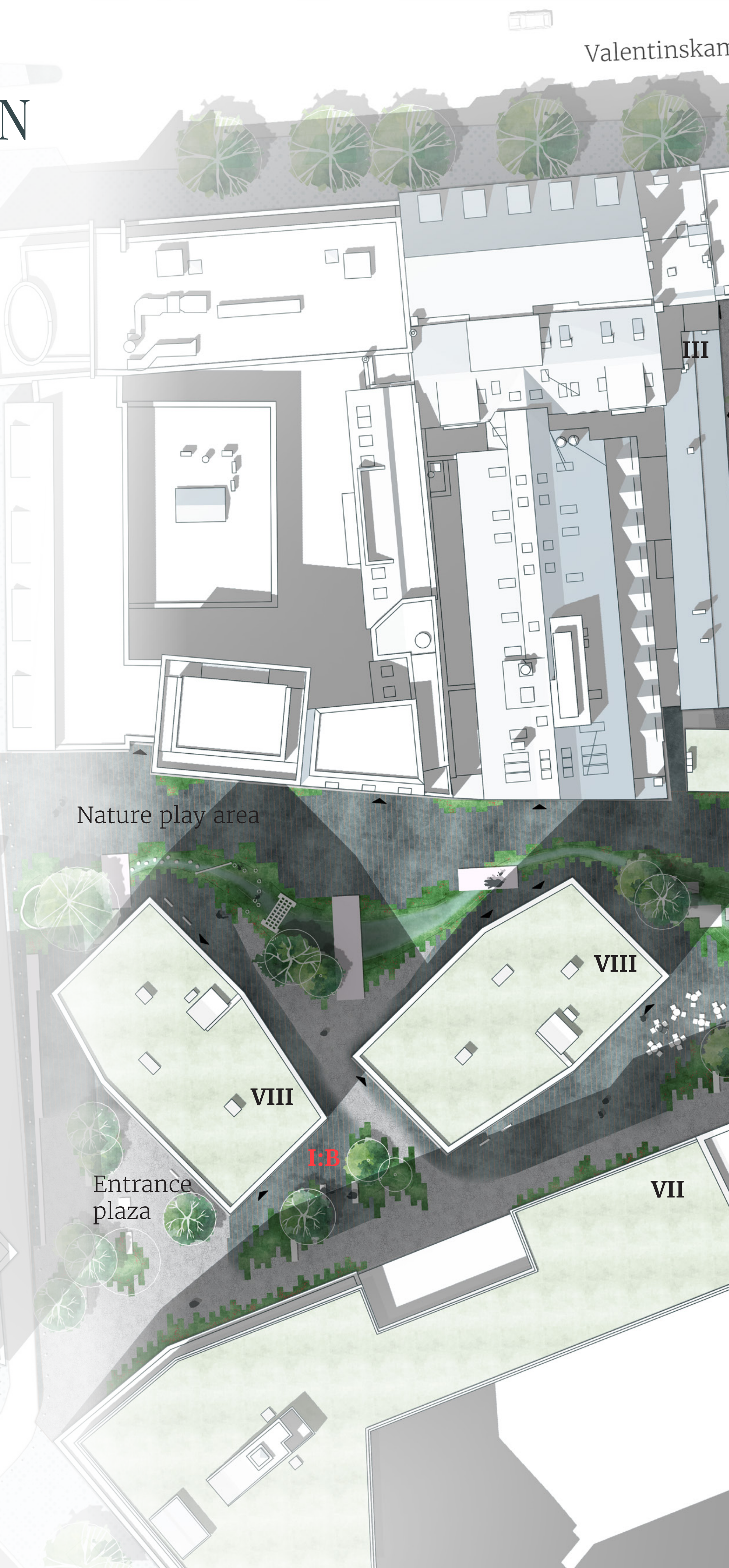
Ill. 65 Section B-B’ - Design
Source: Own Image



Ill. 64. Overview of Sections – Design
Source: Own Image
Datasets:
Buildings - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2024), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de/opendata/ALKIS_Liegenschaftskarte/ALKIS_Liegenschaftskarte_ausgewaehlteDaten_HH_2024-10-05.zip (Accessed 14.02.2025)
Roads - Freie und Hansestadt Hamburg, Behörde für Verkehr und Mobilitätswende (2022), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), [URI] https://daten-hamburg.de//infrastruktur_bauen_wohnen/feinkartierung_strasse/Feinkartierung_Strasse_HH_2022-03-25.zip (Accessed 14.02.2025)

MASTERPLAN

To reduce the separating impact of the Speckstraße and connect the Gängeviertel area with the Brahmsquartier, a green thread, that retains water in case of extreme weather events, is meandering like a river through the site, acting as a zipper that ties the area together. This meandering river opens on each peak of a sweep to transform into a multifunctional space, both for additional water retention but also as a recreational space in the centre of the area. At the southwest entrance of the site, a small plaza invites visitors to stay. The northwest corner of the site features a playground integrated into the meandering river concept allowing for play in the green. Aligning with the previous flow and heat island analysis, the original pavement is stretching through the area along the office buildings from west to east and up into the cultural site of the Gängeviertel. Here, a minimal intervention, except for the installation of a movable green shading system, allows for a flexible use of the space as an area for markets and events. Further east, the new urban gardening has been placed, intended for the local community to work together. Water from roofs is harvested in tanks, that can be used for the garden. The east entrance of the site is the lowest point of the site and thereby used as the final basin of the central water flow. Here, an infiltration basin is used to remove pollutants, while an emergency discharge improves performance for heavy rain-events.

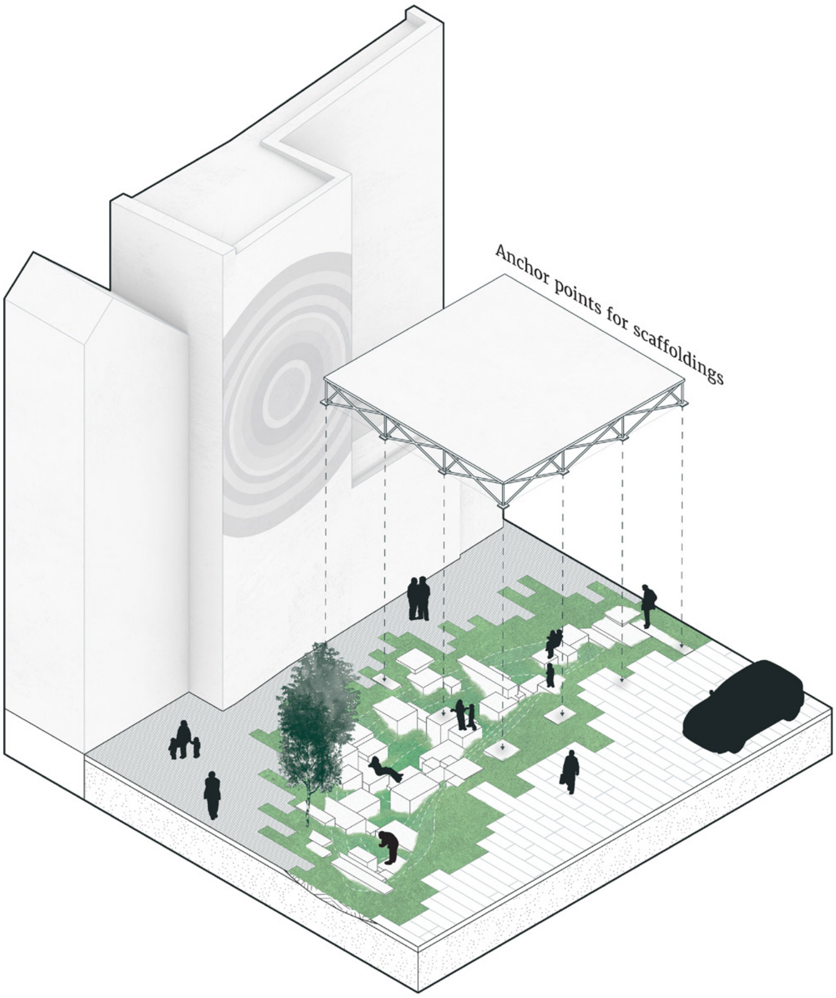


Scale
1:500

Ill. 66. Masterplan of Gängeviertel, 1:500
Source: Own Image
Datasets:
3D-Buildings (Changed) - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2023), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), https://daten-hamburg.de/opendata/3d_stadtmodell_lod3/LoD3-HH_Area1_2023_12_14.zip (Accessed 17.02.2025)

mp
VI
V
Urban gardening
V
V
V
I:C
IV
V
IV
Event
space
I:A
IV
Speckstraße
VII
Caffamacherreiher
XIII

ISOMETRICS



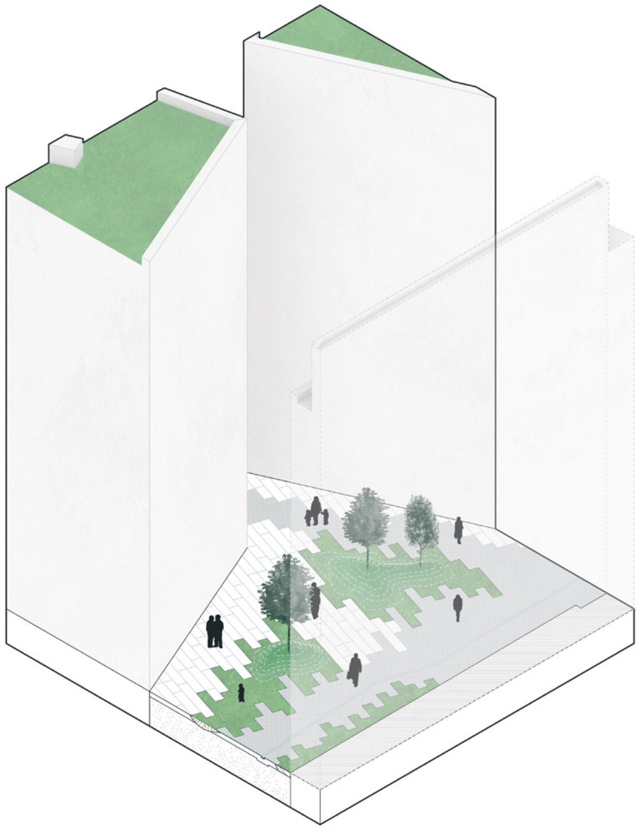
Ill. 67. Detail Isometric A – Multi-functional Rain Basin
Source: Own Image
Dataset: See Ill. 69

Isometric A

The space at Gängeviertel is already limited by the building density in the area. As such, the goal has been to integrate the rainwater-management into the cultural usage of the historical site. The square at Gängeviertel has been identified as thermally uncomfortable on hot summer days yet offering plenty of open space for water elements and vegetation to improve on temperatures. However, as the space is currently used for urban gardening and otherwise utilized as an event area, reserving the space solely for managing rainwater would hinder its cultural purpose. For this reason, the design presented introduces a rain basin with a volume of 45 m³ (see appendix D.2, Rain Basin 2), accessible via stepping stones. Similar to the Rain Basin at Brahmsquartier, these stones afford daily leisure activities and the placement of objects like planters. Additionally, some stones have been placed to provide stable footing for the construction of scaffoldings in the case of an event.

Isometric B

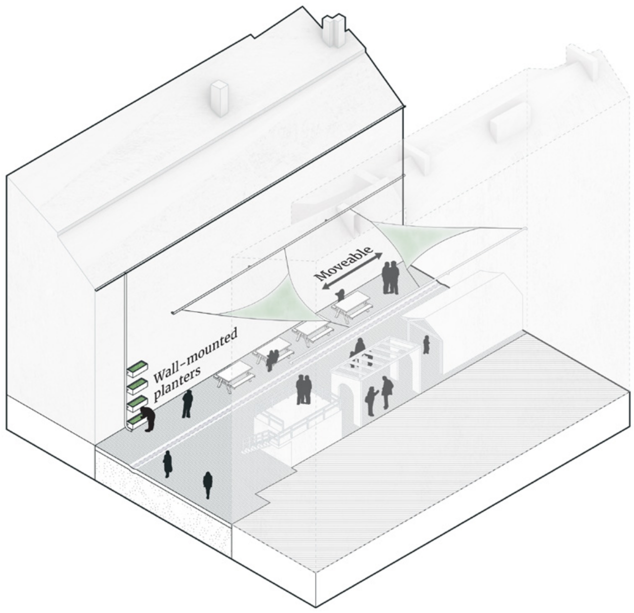
The existing pavement has been used as a character for already thermally comfortable areas. In thermally uncomfortable areas, a new, light and cool pavement is used to reflect radiation. The contrast in colour also aids in wayfinding, as the darker pavement indicates the more urban, unnatural environment, while the lighter pavement is used for the central green thread. On top, several green islands are placed throughout the side, to mimic walking through a flowing, natural landscape. As part of the sensation, the islands are different in topography. Due to the proximity of the underground garage, this also gives the newly introduced trees and other vegetation more room to grow and thrive.



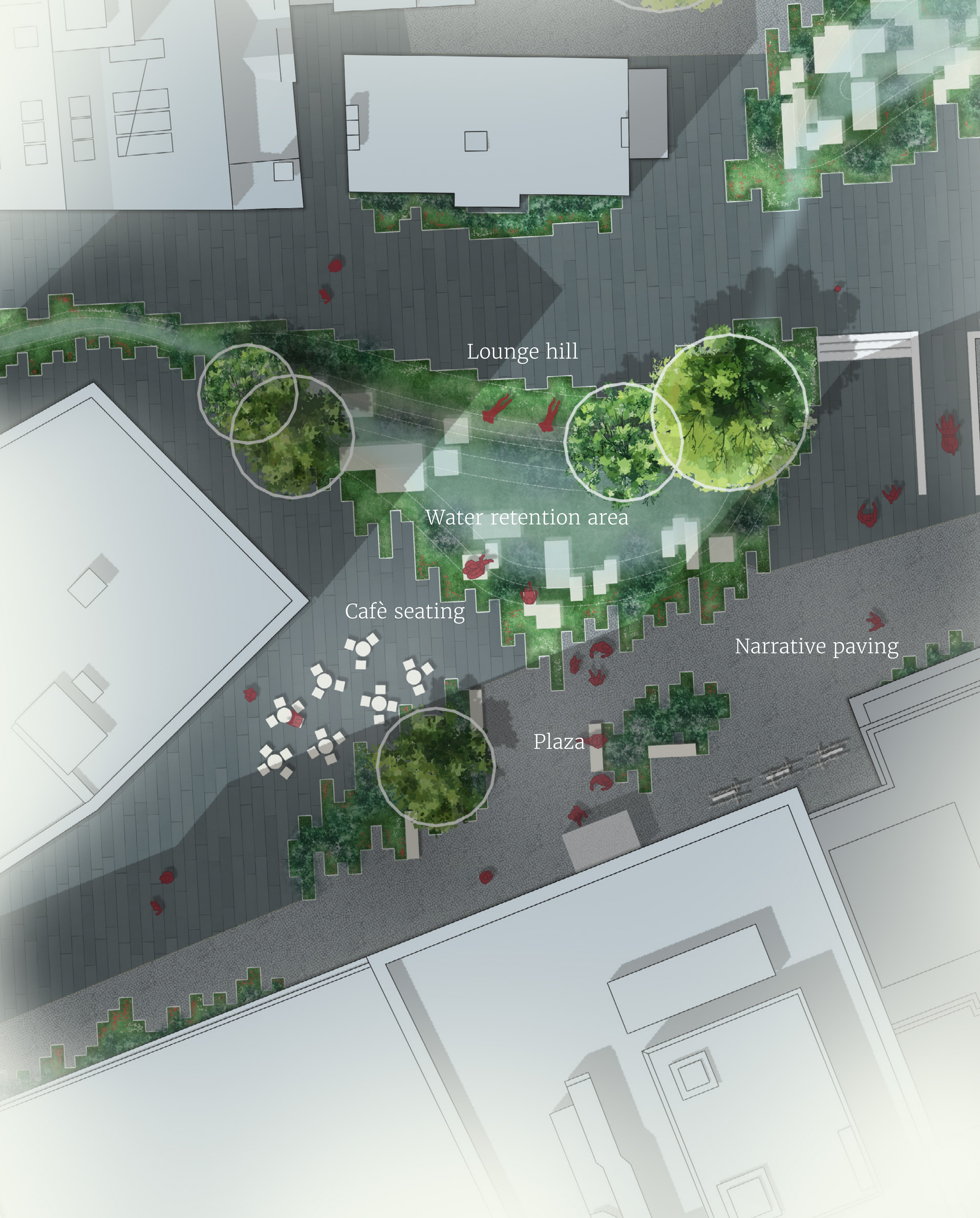
Ill. 68. Detail Isometric B – Landscape structure
Source: Own Image
Dataset: See Ill. 69

Isometric C

The narrowness and difficult soil conditions of Gängeviertel limit the implementation of rainwater-management systems. In addition, regular events require space for visitors and the installations necessary for the various types of events. Taking this into consideration, the narrow passages at Gängeviertel are fully paved, using the retrieved dark pavement from Brahmsquartier. Rainwater is instead guided to the central system of basins. This enables people to integrate their own desired programming and use space flexibly. From a talk with a local citizen, it was revealed that the people involved a lot of times recycle things if needed and craft new installations themselves (see appendix A). As such, planters can be wall-mounted, using cheap materials and directly receive runoff from roofs. Finally, lightly vegetated canopies are installed and can be moved freely along wall-mounted pipes. Especially on hot summer days, additional shading can create a cool island inside Gängeviertel.



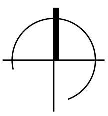
Ill. 69. Detail Isometric C – Gängeviertel event area
Source: Own Image
Datasets:
3D-Buildings (Changed) - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2023), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), https://daten-hamburg.de/opendata/3d_stadtmodell_lod3/LoD3-HH_Area1_2023_12_14.zip (Accessed 17.02.2025)



Ill. 70. Detail plan of Rain Basin at Brahmsquartier, 1:200
Source: Own Image
Datasets:
3D-Buildings (Changed) - Freie und Hansestadt Hamburg, Landesbetrieb Geoinformation und Vermessung (2023), dl-de/by-2-0 (http://www.govdata.de/dl-de/by-2-0), https://daten-hamburg.de/opendata/3d_stadtmodell_lod3/LoD3-HH_Area1_2023_12_14.zip (Accessed 17.02.2025)

DETAIL

Ill. 70 highlights the centre of the Brahmsquartier. This space acts as a node of movement and rest. The central plaza can be used by the residents and workers of the office positioned in the south during breaks and times of leisure. The outdoor seating of the local cafe activates the area additionally. The centre of the site is a generous water retention area, designed with a storage capacity of up to 45 m^3 (see appendix D, Rain Basin 1) that features lush vegetation to create intimate seating in different elevations along the retention space. Further to the north, this water storage area is confined by a hill which is oriented towards the Gängeviertel event space and can be used to relax and lay on but also acts as an additional seating option for big events hosted in the area.



Scale
1:200

PERSPECTIVE

This perspective (see ill. 71) views from the lowered position at Speckstraße onto the new greenspace at Brahmsquartier, looking in the southwest direction.

The hill site, that has been mentioned in the chapter Section, p. 72f., offers a place to relax in the shade under the trees. The varying topography allows for different atmospheres at the site. Moreover, the increase in soil gives additional space for trees to grow. As Balder et al. (2018) suggested, enough space for root growth can reduce maintenance costs for destructed pavement and structures in the long run.

Behind the hill, the illustration depicts the situation of the water retention area currently being filled from a recent heavy rain-event. Therefore, the atmosphere of the site can vary in character, depending on the weather conditions. Further in the back, the outdoor seating from the restaurant has now been framed by vegetation, creating a more intimate place that invites to stay and interact socially.

Ill. 71. Perspective view of Rain Basin at Brahmsquartier
Source: Own Image

SPONGE CITY TOOLBOX

Part of the outcomes of this project is not only to pose a design proposal for the project site, but also to offer guidance on how certain Sponge City tools can be used in other projects, with conditions that might differ from the ones in the current project area. These tools are linked to their:

- **Hydrological performance in relation to the space needed**
- **Ability to remove pollutants**
- **Cost-Effectiveness**
- **Effect on thermal Comfort**

Higher is better

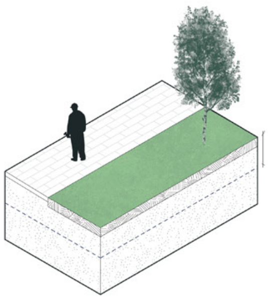
These scores are based on the calculations and used inputs collected for the Sponge City simulation (see appendix C.4 - C.6). Additionally, based on the collected information on measurements to enhance microclimate, their respective effect on thermal comfort at pedestrian level is evaluated (see appendix C.8 for details).

Vegetation is one of the most dominant factors in reducing local heat through an improvement in evapotranspiration. This effect can be strengthened by increasing the density of green space (Jansson et al., 2007; Perini & Magliocco, 2014). In that sense, trees are most effective in improving thermal comfort by providing huge surface areas for evapotranspiration, in combination with shading, which lowers temperatures of surrounding surfaces (Hiemstra et al. 2017).

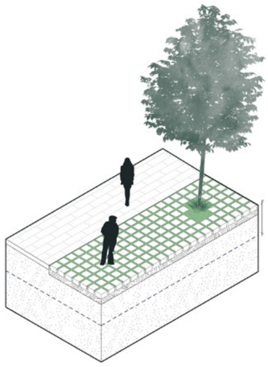
Sponge City tools allow to utilize and harvest rainwater locally, using natural processes and leading to a removal of paved areas. As such, tests on trees in rainwater-management systems have shown tremendous success, as growth of these trees was twice as fast as trees with less access to water (Grey et al., 2018). Open soil shows higher soil-moisture contents, leading to a better availability of water for vegetation and increasing the effect of evapotranspiration. While being slightly less effective, permeable pavements are a good alternative for spaces that need to be paved (Fini et al., 2017). Here, designer must be wary, that giving vegetation room to grow prevents the physical destruction of pavements in the long run and reduces cost for maintenance (Balder et al., 2018). However, bad local soil conditions and waterlogging in facilities that receive high amounts of water (e.g. infiltration basins, rain basins) can potentially harm trees (Grey et al., 2018). In hindsight, DWA (2005; 2013) suggests water to be stored only for short amounts of time to mitigate re-sedimentation and clogging of soil. In connection, findings suggest that the positive effect of small open waterbodies on thermal comfort is limited by an increase in air-humidity, making it a rather aesthetic choice, yet potentially limiting tree growth (Teshnehdel et al., 2022). Instead, infiltration trenches and rain gardens can be equipped with subsurface drains, being used when infiltration rates of the subsequent soil are low and waterlogging occurs. On the other hand, Pallasch et al. (2016) introduced a technical variant for these systems, that keeps water available for trees underground, even during extended dry periods.

When horizontal space is scarce, there are several facilities that can be placed subsurface. Yet, their ability to remove pollutants is unsatisfying and microclimate is not affected by the processes mentioned. Their contribution restricts to improving local groundwater reservoirs (DWA, 2005). Instead, green roofs utilize already occupied building space, while integrating more green space and reducing the energy-demand of buildings. For additional green space, green facades are shown to be more effective for pedestrian thermal comfort than green roofs due to being placed at pedestrian levels (Pfoser & Jenner, 2014; Perini & Magliocco, 2014). Temperatures along these facades can be reduced by up to 1,3 °C (Wong et al., 2010). However, the hydrological performance of these systems has shown to be limited, compared to subsurface systems.

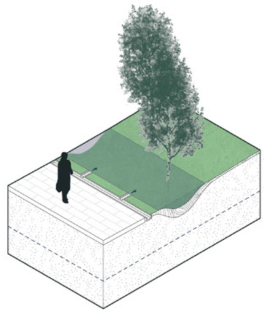
Cisterns are a good complementary tool to reduce the use of fresh water. Even so, the immediate impact on thermal comfort is low and hydrological performance uncertain, due to not emptying out after a rain-event (DIN 1989-100:2022-07, 2022). Yet, harvested water used for gardening and vegetation complements a holistic local treatment of rainwater.



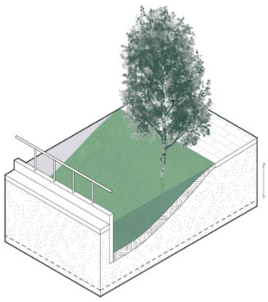
Grass Strip
Infiltration
kfmin: >= 5*10⁻⁵ m/s



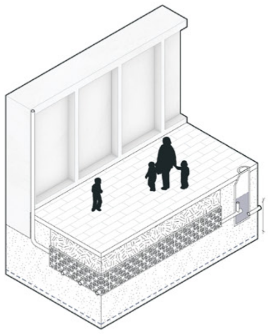
Permeable Pavement
Infiltration
kfmin: >= 5*10⁻⁵ m/s



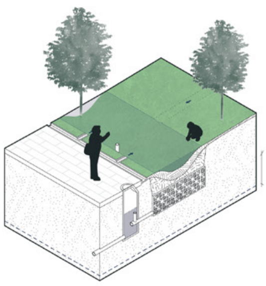
Grass Swale
Infiltration / Storage
kfmin: >= 5*10⁻⁶ m/s



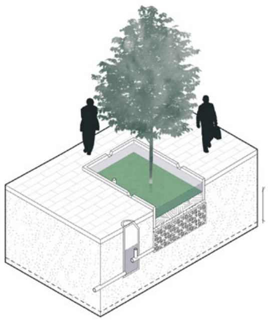
Infiltration Basin
Infiltration / Storage
kfmin: >= 1*10⁻⁵ m/s



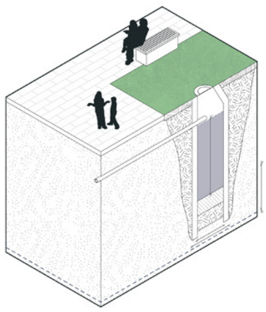
Infiltration Chamber
Infiltration / Storage / Discharge
kfmin: >= 5*10⁻⁶ m/s
kfmin: < 1*10⁻⁶ m/s (discharge)



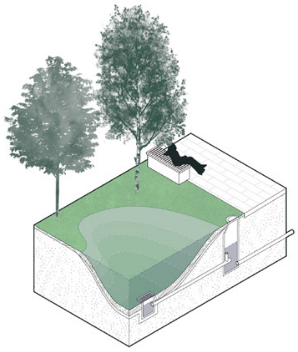
Infiltration Trench
Infiltration / Storage / Discharge
kfmin: >= 5*10⁻⁶ m/s
kfmin: < 1*10⁻⁶ m/s (discharge)



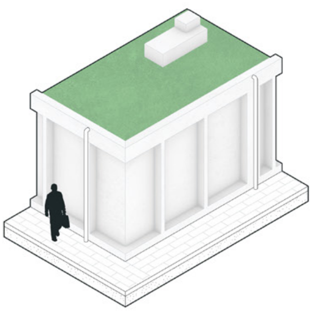
Rain Garden
Infiltration / Storage / Discharge
kfmin: >= 1*10⁻⁶ m/s
kfmin: < 1*10⁻⁶ m/s (discharge)



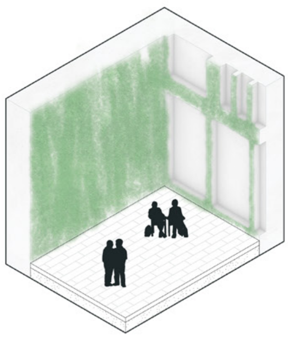
Infiltration Pit
Infiltration / Storage
kfmin: >= 5*10⁻⁶ m/s



Rain Basin
Storage / Discharge
kfmin: ---

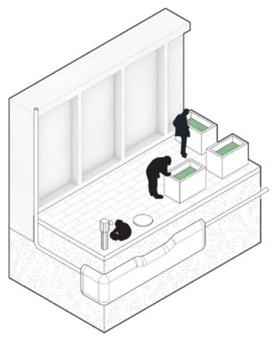


Green Roof
Storage
kfmin: ---



Green Faccade

kfmin: ---



Cistern
Harvest

kfmin: ---

Ill. 72. Sponge toolbox with comparison of different tools regarding their cost and different performance factors
Source: Own Image (see appendix C for details)

EPILOGUE

CONCLUSION

This thesis set out to challenge conventional planning approaches and improve climate resilience and pedestrian comfort through the integration of Sponge city principles. Given the increasing complexity and requirements on urban design, the integration of microclimate simulations and sponge city optimization in the early design stages has proven valuable in supporting more informed decision-making. Using the Gängeviertel and Brahmsquartier as a case study, this thesis showcases how climate adaptation, cultural heritage, and a human-centred design can be developed in a small-scale urban context, contributing to a slowly growing network of urban resilience. By utilizing microclimate simulations and optimization for sponge city tools, the presented iterative workflow can effectively produce a design proposal that is founded in measured scientific data, rather than architectural intuition, offering a replicable standard for microclimate performances in a design. By doing so, this project managed to identify and explore site-specific limitations for the implementation of a local rainwater-management. Identifying limitations is not only helpful in generating valid possible design solutions, which can then be discussed internally, but also guide the architect's decision-making. Here, the computer-aided approach helps in investigating the project-specific design space more effectively, narrowing down possible solutions and testing assumptions with real-world implications. While the project evolves and decisions are made, parameters, such as materials or the depth of rainwater-management systems, can be adjusted accordingly. Moreover, by assessing the possibilities for the implementation of Sponge city principles, synergies with thermally uncomfortable areas can be assessed and attention put towards these areas. Ultimately, using the site of Gängeviertel as a case study, this project has provided insights on how architects can effectively make decisions on complex interactions between managing rainwater and creating thermally comfortable space, while considering social aspects and aesthetics.

As cities around the world continue to require climate adaptation in increasingly urbanized areas, the outcomes of this thesis underscore how sponge city principles, coupled with microclimate simulations can be investigated for their specific context and synthesised in compact urban spaces to enhance resilience and pedestrian comfort. Moreover, the introduced sponge city toolbox provides a first foundation for upcoming projects, promoting initial ideas and guiding decision-making.

REFLECTION

During this project, the integration of sponge city principles and microclimate simulations early in the project led to meaningful results, providing a framework for the design process and references to meet set performance standards. This ensures that future projects have a meaningful impact and truly improve aspects like thermal comfort for pedestrians and water management. That being said, several limitations and insights were recognized during the process of designing that should be reflected and are important to be acknowledged.

One critical aspect is the already mentioned simplification and generalization of the simulations. This is true for the sponge city optimization, as most objectives had to be abstracted and the hydrological performance was set to fixed values. Additionally, limitations on hardware caused crashes and limited the amounts of details for the performed simulations. As an example, geometry had to be simplified for the microclimate simulation, and material conditions for the urban landscape and surrounding building were left out entirely or homogenized. Even still, depending on the details used, either simulation could take up several hours.

Regardless, as also suggested by Østergård et al. (2016), the amount of available data was limited. Uncertainties arose regarding specific thermal properties of materials at the site, or detailed soil conditions, necessary to evaluate infiltration performances. Ultimately, this led to assumptions as a base for decision-making, which might be part of the reason why even after integration of sponge city principles, only a marginal temperature difference could be simulated. Incorporating personal experience, combined with on-site knowledge, can enhance the process of decision-making and reduce false assumptions. An example are the conversations with Martin from the Baukommission, who provided insights on the bad quality of the soil, that previously wasn't recognized by the available data.

As such, the outcome of the introduced simulations should always be interpreted critically and reflected upon. Even with good input data available, the simulation models itself are only abstract representation of reality, as uncertainties outside of their capabilities exist (Østergård et al., 2016). Still, there is more to a good design than meeting performance standards and architects should consider the full, non-simulated picture, when making decisions. Concludingly, while simulations and data analysis are valuable tools in designing resilient urban spaces, they are only one part of the puzzle and cannot substitute for local expertise and site-specific insights. Especially when dealing with historically layered sites like the project site, lived experience is the key to making great design.

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Supervisor´s name: **Lea Holst Laursen**
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APPENDIX

APPENDIX A: CONVERSATION WITH MARTIN

Appendix A, Core information's derived from a conversation with Martin, Part of the “BauKommission/ Gängeviertel Assossiation 2010 eG) from 27.03.2025, translated from german into english:

The project follows a do-it-yourself (DIY) approach and emphasizes sustainability in outdoor spaces, experimenting with recycled materials such as repurposed bathtubs for facade greening. Work is carried out by volunteers and with a limited budget.

Challenges related to green spaces include poor water infiltration due to compacted soils from historical construction, and subsoils made mostly of rubble, making deep digging difficult. High foot traffic also hampers the feasibility of long-term greening, as the neighborhood sees heavy daily visitor numbers.

Legal and financial constraints stem from the buildings being financed as social housing through the Integrated Development Concept (IEK), which restricts the budget. Greening features like solar panels, facade greenery, and cisterns are often envisioned but rarely affordable. There are also conflicts with the district office over safety requirements (such as fall protection and fire safety), which are difficult to integrate into the project and are often too costly.

Given that renovations will continue for another 10 to 15 years, temporary and mobile greening solutions are prioritized. These include movable trees in heavy-duty grid boxes to allow flexible responses to construction and events.

Neighborhood relations pose another challenge: the building opposite the vacant lot is a high-end office space owned by Allianz, and the adjacent residential buildings are privately owned condominiums. The surrounding street area, including the underground garage, is private property. Despite the street having potential as a shared green or communal space, the property owners show no interest in cooperation, citing concerns about noise and use. Their property rights give them final authority, further hindering collaborative development.

The project remains community-driven, with strong public involvement. Dialogues with the district office are held as needed to reconcile regulations with local conditions.

Upcoming projects include a waste collection house at the Family House, a mural with potential facade greening via planters (still one of several ideas), a steel platform at the “Speckstraße” building, a 10,000-liter cistern collecting roof rainwater to irrigate outdoor areas—particularly the mobile trees—and the use of IBC containers for manual water storage and irrigation.

APPENDIX B.1 COOLING PAVEMENT

Pavement Type	Mechanism	Cooling Potential	Key Benefits	Limitations / Challenges	Sources
Reflective Pavements	Increase surface albedo to reflect more solar radiation	Lowers surface temp. by 10-15 °C (Qin, 2015)	Simple implementation; Significant Reduction in surface temps.	Potential glare; May increase surrounding building temps.	Qin, 2015; Yang et al., 2015
• Chip/slurry seal	Light-coloured aggregate layers	Increase albedo by up to 0.20	Cost-effective; Retro-fitting possible	Albedo degrades with age and soiling	Levinson & Akbari, 2002
• Reflective Concrete	White cement and slag-based mixes	Increase albedo by up to 0.80	Long-lasting; Durable	Limited flexibility; High costs	Levinson & Akbari, 2002
Evaporative/ Permeable Pavements	Enhance evaporation through water retention and permeability	Lowers surface temp. by 4-12 °C	Cools both, surface and air; Reduces water runoff	Requires maintenance to prevent clogging; May not suit heavy traffic areas	Haselbach et al., 2011
Phase Change Material (PCM) Pavements	Absorbs latent heat during phase transitions (e.g. melting paraffin)	Reduces heat build-up during peak hours	Maintains lower surface temps. without external energy input	Leakage, degradation, cost and compatibility with asphalt remain challenges	Wang et al., 2022
Polymer-Based Reflective Coatings	Coatings with NIR-reflective nanoparticles in epoxy/ acrylic matrix	Lowers surface temp by 8-20 °C	Strong cooling; Adaptable to existing asphalt	UV degradation, adhesion issues and high cost require precision application	Wang et al., 2022
Thermochromic Coatings	Changes albedo with temperature (higher in summer, lower in winter)	Variable change (Difference of up to 6 °C)	Adaptation to seasonal changes	High cost, photodegradation and strength loss when integrated into concrete	Karlessi et al., 2009
Nature-Based Surfaces (e.g. vegetated pavements)	Shading and evapotranspiration from integrated vegetation	Moderate; Enhances air cooling	Improves thermal comfort, biodiversity, air quality	Requires space, water and maintenance; Not ideal for high-load surfaces	Hayes, et al., 2022

Table 1: Cooling pavement overview

APPENDIX B.2 THERMAL AND RADIATIVE MATERIAL OVERVIEW

Pavement Type	Conductivity (W/m*K)	Density (kg/m³)	Specific Heat (J/kg*K)	Roughness	Thermal Absorption	Solar Absorption	Visible Absorption	Sources
Concrete	1,20 – 2,00	2300 – 2500	900 – 1100	Smooth	0,85 – 0,95	0,60 – 0,80	0,70 – 0,90	Petkova-Slipets & Zlateva, 2018; Kaloush et al., 2018; Shamsaei et al., 2024
Asphalt	0,28 – 1,57	2100 – 2300	920 – 1000	Smooth	0,90 – 0,95	0,90 – 0,95	0,90 – 0,95	Narmanova et al., 2023; Alleman & Heitzmann, 2019; Shamsaei et al., 2024
Cobblestone	1,00 – 1,50	2200 – 2400	850 – 900	Rough	0,80 – 0,90	0,75 – 0,85	0,80 – 0,90	Kaloush et al., 2018; Shamsaei et al., 2024
Soil	0,50 – 1,20	1400 – 1600	800 – 1200	Very Rough	0,85 – 0,95	0,85 – 0,95	0,85 – 0,95	Narmanova et al., 2023
Grass / Turf	0,40 – 0,60	1100 – 1300	1500 – 2000	Moderate	0,70 – 0,85	0,70 – 0,80	0,70 – 0,80	Shamsaei et al., 2024
Vegetation	0,30 – 0,50	900 – 1100	1800 – 2500	Variable	0,60 – 0,75	0,60 – 0,70	0,60 – 0,70	Shamsaei et al., 2024
Cooling Pavement	0,50	1600 – 1900	850	Rough	0,50 – 0,60	0,30 – 0,40	0,40 – 0,50	Kaloush et al., 2018; Minnesota Pollution Control Agency, 2022; Tuan et al., 2024

Table 2: Thermal and radiative overview of materials used in the thermal outdoor comfort analysis

APPENDIX C.1

C.1 VARIABLES

$A_{E,k}$	Area of catchment [m²]
A_u	Paved, sealed area [m²]
A_S	Area of infiltration [m²]
A_{low}	Lower Area of pool [m²]
A_{top}	Top area of pool [m²]
Ψ_m	Discharge coefficient
C_i	Cost for a single system per unit [€/A_u]
C_{Ov}	Cost for a single system [€]
C_{total}	Combined costs of all Facilities [€]
D	Duration [min]
d_a	Outer diameter [m]
d_i	Inner diameter [m]
h_S	Distance from lowest point to Groundwater [m]
k_f	Soilspecific permeability [m/s]
l_s	Length of pool bottom [m]
m	Slope gradient where m is 1:m
P_i	Pollution score for a single system (higher is better)
P_{total}	Combined Pollution score (higher is better)
$q_{dr,k}$	Specified maximum discharge per hectare [l/(s*ha)]
Q_{DR}	Rate of controlled discharge [m³/s]
Q_S	Rate of infiltration [m³/s]
$Q_{S,mid}$	Average rate of infiltration [m³/s]
r_D	Rain yield factor for the duration D
S_R	Storage coefficient, which is affected by porosity
V_{Ov}	Overall stored, infiltrated and discharged amount of water by a single system [m³]
V_M	Stored amount of water for a grass swale [m³]
V_R	Stored amount of water for an infiltration chamber [m³]
V_S	Stored amount of water for an infiltration pit [m³]
V_T	Stored amount of water for a rain garden [m³]
V_{total}	Overall stored, infiltrated and discharged amount of water in an area [m³]
w_s	Width of pool bottom [m]
x	Decision Variable used in the simulation, specified as usage of area [m²]
z	Waterdepth [m]

C.2 RAIN YIELD

Formula

$$A_U = \sum A_{E,i} * \Psi_{,m,i}$$

$$A_U = 0{,}85\ ha * 0{,}832$$

$$A_{U,roof} = 0{,}34\ ha * 1{,}000$$

$$Volume\ A_U = r_D * D * A_U * f_Z * 0{,}06$$

$A_{E,i}$	Area of sub-catchment
$\Psi_{m,i}$	Average discharge coefficent for a sub-catchment area
$A_{U,roof}$	Paved, sealed area for all roofs

Notes

- Refer to DWA (2005: 21) for detailed values on the discharge coefficient

$A_{E,k}$ [ha]	$A_{E,roof}$ [ha]	A_u [ha]	$A_{u,roof}$ [ha]	$\Psi_{m,i}$	$\Psi_{m,roof}$
0,85	0,34	0,71	0,34	0,832	1,000

Table 1: Constants for the calculation of rain volume

		T_N: 1a			T_N: 2a			T_N: 5a			T_N: 10a		
[min]	[h]	Rain yield factor r_D [l/(s*ha)]	Volume A_U [m³]	Volume $A_{U,Roof}$ [m³]	Rain yield factor r_D [l/(s*ha)]	Volume A_U [m³]	Volume $A_{U,Roof}$ [m³]	Rain yield factor r_D [l/(s*ha)]	Volume A_U [m³]	Volume $A_{U,Roof}$ [m³]	Rain yield factor r_D [l/(s*ha)]	Volume A_U [m³]	Volume $A_{U,Roof}$ [m³]
5		183,3	47	22	223,3	57	27	280	72	34	326,7	84	40
10		120	61	29	145	74	35	183,3	94	45	213,3	109	52
15		91,1	70	33	111,1	85	41	140	107	51	163,3	125	60
20		75,8	77	37	92,5	95	45	115,8	118	57	135	138	66
30		57,2	88	42	70	107	51	87,8	135	64	102,8	158	75
45		43,3	100	48	53	122	58	66,7	153	73	77,8	179	86
60		35,6	109	52	43,3	133	64	54,4	167	80	63,3	194	93
90		26,9	124	59	32,8	151	72	41,1	189	91	48	221	106
120	**2**	21,9	134	64	26,7	164	78	33,6	206	99	39,2	240	115
180	**3**	16,5	152	73	20,1	185	89	25,3	233	111	29,4	271	130
240	**4**	13,5	166	79	16,4	201	96	20,6	253	121	24,1	296	142
360	**6**	10,1	186	89	12,3	226	108	15,5	285	137	18,1	333	160
540	**9**	7,6	210	100	9,3	257	123	11,6	320	153	13,6	375	180
720	**12**	6,2	228	109	7,6	280	134	9,5	350	167	11,1	409	196
1080	**18**	4,7	259	124	5,7	315	151	7,1	392	188	8,3	458	219
1440	**24**	3,8	280	134	4,6	339	162	5,8	427	204	6,8	501	240

Table 2: Calculated rain volume for different rain-events

C.3 RAINWATER-MANAGEMENT SYSTEMS

Facility	Information	
A1	Water is solely being infiltrated on vegetated soil or unpaved urban areas (DWA, 2005). $k_{f min}$: >= 5*10^-5 m/s	**Grass Strip**
A2	These pavements allow water to seep through and infiltrate into the underlying soil, while being able to carry higher loads compared to open soil (DWA, 2005). Due to aging processes, its ability to infiltrate water decreases over time, making it less reliable than grass strips (Borgwardt, 2006). According to DWA (2005), they don't qualify as only tools for rainwater-management and must be combined with others. $k_{f min}$: ---	**Permeable Pavement**
A3	These facilities, in addition to conventional infiltration, allow water to be stored for short periods of time with levels of up to 30cm. For that reason, these systems can manage more water than conventional grass strips (DWA, 2005). $k_{f min}$: >= 5*10^-6 m/s	**Grass Swale**
A4	Infiltration Basin- These systems are constructued similarly to Grass Swales, but higher water levels (>30cm) allow for more water to be stored. However, this requires higher infiltration rates of the pending soil to prevent waterlogging (DWA, 2005). $k_{f min}$: >= 1*10^-5 m/s	**Infiltration Basin**
A5/B5	Storage modules, or porous materials like gravel are placed underground to store water effectively. This water can then slowly infiltrate into the pending soil. Water is either induced directly through pipes (completely hidden facility), or seeps in through a surface opening. This system is commonly used to preserve surface area, when space is scarce. Yet, its ability to remove pollutants from rainwater is small, only allowing runoff from little contaminated surfaces (e.g. roofs) to be connected to these modules. This is to prevent groundwater contamination. In special cases with bad infiltration rates, a controlled discharge into the sewer system increases its performance (B5) (DWA, 2005). A5 - $k_{f min}$: >= 5*10^-6 m/s (without discharge) B5 - $k_{f min}$: < 1*10^-6 m/s (with discharge)	**Infiltration Chamber**
A6/B6	This system combines a grass swale with underlying infiltration chambers, increasing its storing volume and allowing its use in soil with slower infiltration rates. Because the water needs to pass the grass swale first, the pollutant removal rate is much better compared to only using infiltration chambers. In special cases with bad infiltration rates, a controlled discharge into the sewage system increases its performance even further (B6). Additionally, an overflow from the grass swale, down to the storage modules, increases performance as well (DWA, 2005). A6 - $k_{f min}$: >= 1*10^-6 m/s (without discharge) B6 - $k_{f min}$: < 1*10^-6 m/s (with discharge)	**Infiltration Trench**
A7/B7	This is a special system derived from infiltration trenches. Similarly, it combines the storage capacity of a grass swale and infiltration chambers. Otherwise, the grass swale, instead of being designed like a natural depression, is framed in concrete, with the garden area being lowered straight down by up to 30cm. This increases its storage capacity and lowers the surface area necessary. This system also allows to be directly connected to the sewage system (B7), to compensate for slow infiltration rates (DWA, 2005; SenUVK, 2018). A7 - $k_{f min}$: >= 1*10^-6 m/s (without discharge) B7 - $k_{f min}$: < 1*10^-6 m/s (with discharge)	**Rain Garden**
A8	Infiltration pits are made of circular concrete shafts, leading deep into the ground. Water is stored in these pits and then infiltrated into the soil. Due to being underground, surface area is preserved. This system is required to be equipped with a filter layer, yet very low pollutant removal rates only allow for runoff with low contamination to be induced. Due to this, the minimum distance to groundwater is also increased from the conventional 1m to 1.5m to protect the groundwater (DWA, 2005). $k_{f min}$: >= 5*10^-6 m/s	**Infiltration Pit**
A9	Basins are constructed to store water and reduce the burden on the sewage system by allowing a controlled discharge. The controlled discharge must be determined together with local authorities. Construction wise, rain basins can be built with concrete, or as a sealed earth construction. Additionally, they can be designed to stay dry after rain-events or always hold water. While large basins, with long standing water, can lead to sedimentation of pollutants, the basic variant of this system is generally not designed to clean runoff. However, it can be adjusted to improve pollutant removal rates, though this generally results in higher usage of surface area (DWA, 2013). $k_{f min}$: ---	**Rain Basin**

Facility	Information	
A10	Utilizing the space on roofs, this system introduces a green component to buildings. On a technical level, it is differentiated between extensive and intensive greening, with the later one introducing more organic mass and retentive potential by using thicker soil substrates. Regarding water-management, this system can be modified to store additional amounts of water in its substrate layers. However, its use is limited by a building's static and roof pitch. While possible to be placed on roofs with angles of up to 45°, for good retentive properties, a maximum of 10° is favourable (Pfoser & Jenner, 2014). k_{fmin}: ---	**Green Roof**
	Extra Facilities (not used for simulation)	
S1	This system is installed along the facades of buildings. Construction-wise, vegetation can either be planted earthbound, or in vertically placed systems. Scaffoldings can guide plants to grow vertically and improve stability. While having no retentive properties regarding rainwater runoff, they improve the local water-cycle through evapotranspiration (Pfoser & Jenner, 2014). k_{fmin}: ---	**Green Faccade**
S2	Cisterns allow rainwater to be harvested in tanks and used locally. Examples are the use for gardening or toilets. They can be installed underground and accessed with pumps, as well as above ground. To remain clean, only runoff from roofs should be used and filters installed. The size depends on the amount of water that is needed and available roof area (DIN 1989-100:2022-07, 2022). k_{fmin}: ---	**Cistern**

Table 3: Short explanation of the various rainwater-managements systems presented in this report

C.4 HYDROLOGICAL CALCULATIONS

A1 Grass Strip

.germ: “Flächenversickerung”

Notes

* Calculation based on DWA (2005)

Parameter

D	120 [min]
k_f	5*10^-5 [m/s]

Formula

$$Q_{S,mid} = \frac{k_f}{2} * x$$

$$V_{Ov} = Q_{S,mid} * D * 60$$

A2 Permeable Pavements

.germ: “Wasserdurchlässiges Pflaster”

Notes

* Calculation based on DWA (2005)
* Amount of infiltration lowered to 25% of A1, due to graduate long-term performance loss from clogging (Borgwardt, 2006)

Parameter

D	120 [min]
k_f	5*10^-5 [m/s]

Formula

$$Q_{S,mid} = \frac{k_f}{2} * x$$

$$V_{Ov} = Q_{S,mid} * D * 60 * 0.25$$

A3 Grass Swale

.germ: “Versickerungsmulde”

Notes

* Calculation based on DWA (2005)
* Calculation of adjusted storage volume based on a squared truncated pyramid
  » lower m-value due to less safety concerns

Parameter

h_S	7,9 [m]
D	120 [min]
k_f	5*10^-5 [m/s]
m	2
z	0,3 [m]

Formula

$$A_{top} = x$$

$$A_{low} = l_s * w_s = (\sqrt{x} - 2 * z * m)^2$$

$$Q_{S,mid} = \frac{\frac{k_f}{2} * A_{low} + \frac{k_f}{2} * \frac{h_S + z}{h_S + \frac{z}{2}} * A_{top}}{2}$$

$$V_M = \frac{1}{3} * z * [A_{low} + (A_{low} * A_{top})^{\frac{1}{2}} + A_{top}]$$

$$V_{Ov} = V_M + Q_{S,mid} * D * 60$$

A4 Infiltration Basin

.germ: “Versickerungsbecken”

Notes

* Calculation based on DWA (2005)
* Refer to A3 for surface volume
  » Higher m-value for assumed safety reasons

Parameter

h_S	7,2 [m]
D	120 [min]
k_f	5*10-5 [m/s]
m	3
z	1 [m]

Formula

$$Q_{S,mid} = \frac{\frac{k_f}{2} * A_{low} + \frac{k_f}{2} * \frac{h_S + z}{h_S + \frac{z}{2}} * A_{top}}{2}$$

$$V_M = \frac{1}{3} * z * [A_{low} + (A_{low} * A_{top})^{\frac{1}{2}} + A_{top}]$$

$$V_{Ov} = V_M + Q_{S,mid} * D * 60$$

A5 Infiltration Chamber / B5 Infiltration Chamber

.germ: “Rigole” / .germ: “Rigole”

+ DRAIN

Notes

* Calculation based on DWA (2005)
* S_R and z based on values for plastic module Rigofill® Inspect block (FRÄNKISCHE Rohrwerke, 2025)

Parameter

h_S	6,7 [m]
D	120 [min]
k_f	A5: 5*10^-5 [m/s] B5: 5*10^-7 [m/s]
S_R	0.95
$q_{dr,k}$	2 [l/(s*ha)]
z	0,66 [m]

Formula

$$V_R = x * z * S_R$$

$$Q_{S,mid} = \frac{\frac{k_f}{2} * x + \frac{k_f}{2} * \frac{h_s + \frac{z}{2}}{h_s} * x}{2}$$

$$Q_{DR} = \frac{A_{E,k} * q_{dr,k}}{1000}$$

$$V_{Ov} = V_R + Q_{S,mid} * D * 60$$ (A5)

$$V_{Ov} = V_R + Q_{S,mid} * D * 60 + Q_{DR} * D * 60$$ (B5)

$$V_{total} = \sum_{i=A1}^{n=A10} V_{OV,i}$$

B6 Infiltration Trench

+ DRAIN

.germ: “Mulden-Rigolen-System”

Infiltration Trench A6

.germ: “Mulden-Rigolen-Element”

Formula

$$V_R = x * z * S_R$$

$$V_M = \frac{1}{3} * z * [A_{low} + (A_{low} * A_{top})^{\frac{1}{2}} + A_{top}]$$

$$Q_{S,mid} = \frac{\frac{k_f}{2} * x + \frac{k_f}{2} * \frac{h_s + \frac{z}{2}}{h_s} * x}{2}$$

$$Q_{DR} = \frac{A_{E,k} * q_{dr,k}}{1000}$$

$$V_{Ov} = V_M + V_R + Q_{S,mid} * D * 60 ⇨$$

$$V_{Ov} = V_M + V_R + Q_{S,mid} * D * 60 + Q_{DR} * D * 60 ⇦$$

Parameter

h_S	6,7 [m]
D	120 [min]
k_f	A6: 5*10^-5 [m/s] B6: 5*10-7 [m/s]
m	2
S_R	0.95
$q_{dr,k}$	2 [l/(s*ha)
z	0,66 [m]

Notes

- Calculation based on DWA (2005) for A6: Infiltration trench and B6: Infiltration drench with drainage
- Refer to A5/B5 for underground modules
- Refer to A3 for surface volume

B7 Rain Garden

+ DRAIN

.germ: “Tiefbeet”

Rain Garden A7

.germ: “Tiefbeet”

Formula

$$V_T = x * z$$

$$V_R = x * z * S_R$$

$$Q_{S,mid} = \frac{\frac{k_f}{2} * x + \frac{k_f}{2} * \frac{h_s + \frac{z}{2}}{h_s} * x}{2}$$

$$Q_{DR} = \frac{A_{E,k} * q_{dr,k}}{1000}$$

$$V_{Ov} = V_T + V_R + Q_{S,mid} * D * 60 ⇨$$

$$V_{Ov} = V_T + V_R + Q_{S,mid} * D * 60 + Q_{DR} * D * 60 ⇦$$

Parameter

h_S	6,7 [m]
D	120 [min]
k_f	A7: 5*10^-5 [m/s] B7: 5*10^-7 [m/s]
S_R	0.95
$q_{dr,k}$	2 [l/(s*ha)
z	0,66 [m]

Notes

- Calculation based on DWA (2005)--> A7: Infiltration trench / B7: Infiltration trench with drainage
- Technical change to storage volume based on SenUVK (2018)
- Refer to A5/B5 for underground modules
- * Refer to A3 for surface volume

Infiltration Pit A8

.germ: “Versickerungsschacht”

Formula

$$V_S = \pi * \frac{{d_i}^2}{4} * z$$

$$A_S = \pi * \frac{{d_a}^2}{4} + \pi * d_a * \frac{z}{2}$$

$$Q_{S,mid} = \frac{k_f}{2} * A_S$$

$$V_i = V_S + Q_{S,mid} * D * 60 \qquad n_x = \pi * (\frac{d_a}{2} * b)^2$$

$$V_{OV} = n_x * V_i$$

Parameter

b	3
D	120 [min]
d_a	1 [m]
d_i	1,2 [m]
k_f	5*10^-5 [m/s]
z	2 [m]

Notes

- Calculation done for 1 pit based on DWA (2005)
- Number of pits n_x determined for an area x using the formula for a circle
- » chosen buffer-value b allows for sufficient infiltration area for each pit

Rain Basin A9

.germ: “Regenrückhaltebecken”

Formula

$$A_{top} = x$$

$$A_{low} = l_s * w_s = 2 * \sqrt{x} - 2 * z * m$$

$$V_M = \frac{1}{3} * z * [A_{low} + (A_{low} * A_{top})^{\frac{1}{2}} + A_{top}]$$

$$Q_{DR} = \frac{A_{E,k} * q_{dr,k}}{1000}$$

$$V_{Ov} = V_M + Q_{DR} * D * 60$$

Parameter

D	120 [min]
m	3
$q_{dr,k}$	2 [l/(s*ha)]
z	1 [m]

Notes

- Calculation based on DWA (2006)
- Higher m-value assumed for safety reasons

Green Roof A10

.germ: “Dachbegrünung”

Formula

$$V_{Ov} = \frac{x * a}{1000}$$

Parameter

a	30 [l/m²]

Notes

- value a based on an exemplary retention roof from Weissenberge, Hamburg (low thickness with retention space of 40mm) (Bukea, 2022: 2)

Table 4: Hydrological formulas and parameters for various rainwater-management systems

C.5 POLLUTION-CALCULATION

Formula	Notes
$$P_{total} = \sum_{i=A1}^{n=A10} \frac{V_{OV,i}}{V_{total,i}} * A_u * P_i$$	• Pollution calculations are put in relation to the amount of water a facility handles, compared to the total amount of water

Pollution-Score (P_i)			
Facility	**Score**	Sources	Notes
A1	5	DWA (2005: 14)	
A2	2	Borgwardt (2006)	• Clogging leads to lower infiltration and higher surface runoff over time
A3	4	DWA (2005: 14)	
A4	3	DWA (2005: 14)	
A5	2	DWA (2005: 14)	
B5	1	DWA (2005: 14)	• Additional, unfiltered discharge lowers score compared to A5
A6	4	DWA (2005: 14)	
B6	3	DWA (2005: 14)	• Additional, unfiltered discharge lowers score compared to A6
A7	4		• Similar construction as Infiltration trench (A6) (SenUVK, 2018: 23f.)
B7	3		• Similar construction as Infiltration trench with drainage (B6) (SenUVK, 2018: 23f.)
A8	1	DWA (2005: 14)	
A9	1	DWA (2013: 30ff)	• Not constructed to clean (can be upgraded with filter-systems)
A10	5	Pfoser & Jenner (2014: 146-147)	• Filter and harvest potential for fresh rainwater

Table 5: Derived pollution scores for various rainwater-management systems (higher is better)

C.6 PRICE-CALCULATION

Formula	Notes
A1, A3, A4, A5, B5, A6, B6, A7, B7, A8: $C_{OV} = \frac{V_{OV}}{V_{total}} * A_U * C_i$	• Price calculations are put in relation to the amount of water a facility handles, compared to the total amount of water
A9: $C_{OV} = x * z * C_i$	
A2, A10: $C_{OV} = x * C_i$	
$C_{total} = \sum_{i=A1}^{n=A10} C_{OV,i}$	

Price-Data (C_i)					
Facility	Input_1 [€/Au]	Input_2 [€/Au]	**Cost [€/Au]**	Sources	Notes
A1	2,5-10	2-5	4,9	1. BSU (2006: 24) 2. BWI (2015: 23)	
A2	30-40 /m²	45-55 /m²	42,5 /m²	1. BSU (2006: 22ff.)	• based on surface size in [m²] • (1) Lawn pavers; (2) Porous concrete
A3	10	2,5-7	7,4	1. BSU (2006: 24) 2. BWI (2015: 23)	
A4	30	---	18,7	1. BSU (2006: 37)	• constructed similarly to A3 • Value of 30 given for a special variant pond-structure • Average between 7,4 (A3) and 30 chosen
A5	20	5-25	17,5	1. BSU (2006: 33) 2. BWI (2015: 23)	
B5	---	---	23,75		• based on cost difference between A6-B6 = 6,25€ (+12,75 €) for added drainage
A6	15-20	15-25	18,75	1. BSU (2006: 34) 2. BWI (2015: 23)	
B6	27,5	15-30	25	1. BSU (2006: 34) 2. SenUVK (2018: 33)	
A7	15-25	---	20	1. BWI (2015: 23) 2. SenUVK (2018: 33)	
B7	25-40	---	32,5	1. BSU (2006: 34) 2. SenUVK (2018: 33)	
A8	10-25	15-25	18,75	1. BSU (2006: 36) 2. BWI (2015: 23)	
A9	100-400 /m³	---	400 /m³	1. BSU (2006: 42)	• based on volume in [m³] • prices decrease with size, but systems are smaller in dense areas (LFU, 2002: 59)
A10	38 /m²	---	38 /m²	1. BUKEA (2022: p.2)	• based on surface size in [m²] • for a retention roof (40mm)

Table 6: Collected price-data for various rainwater-management systems in €/unit

C.7 CONSTRAINTS - FORMULAS AND LIMITS

(1) Maximum usable area

$$A1 + A2 + A3 + A4 + A5 + B5 + A6 + B6 + A7 + B7 + A8 + B8 + A9 + A10 \leq A_{max}$$

A_{max} Maximum combined extend for all rainwater facilities [m²] --> 5675 m²

(2) Limited Land Use

$$A1, A2, A3, A4, A5, B5, A6, B6, A7, B7, A8, A9, A10 \leq A_{max,n}$$

$A_{max,n}$ Maximum extend for a single rainwater facility [m²]

$A_{max,(A1,A3,A4,A6,A7)}$	110 m²
$A_{max,A2}$	5100 m²
$A_{max,(A5,A8)}$	570 m²
$A_{max,(B6,B7)}$	570 m²
$A_{max,B5}$	1150 m²
$A_{max,A9}$	2400 m²
$A_{max,A10}$	575 m²

(3) Hydrological Target

$$V_{Ges} \leq V_{OV,A1} + V_{OV,A2} + V_{OV,A3} + V_{OV,A4} + V_{OV,A5} + V_{OV,B5} + V_{OV,A6} + V_{OV,B6} + V_{OV,A7} + V_{OV,B7} + V_{OV,A8} + V_{OV,A9} + V_{OV,A10} \leq V_{Ges} + \frac{V_{Ges}}{100} * 10$$

V_{Ges} 206 m³

(4) Limit Water – roofs

$$V_{OV,A5} + V_{OV,B5} + V_{OV,A8} + V_{OV,A10} \leq V_{roof}$$

V_{roof} 99 m³

(5) Minimum size

$$A3, A4, A6, B6, A9 \geq (2 * z * m)^2$$

m Slope [m:1]

z Depth [m]

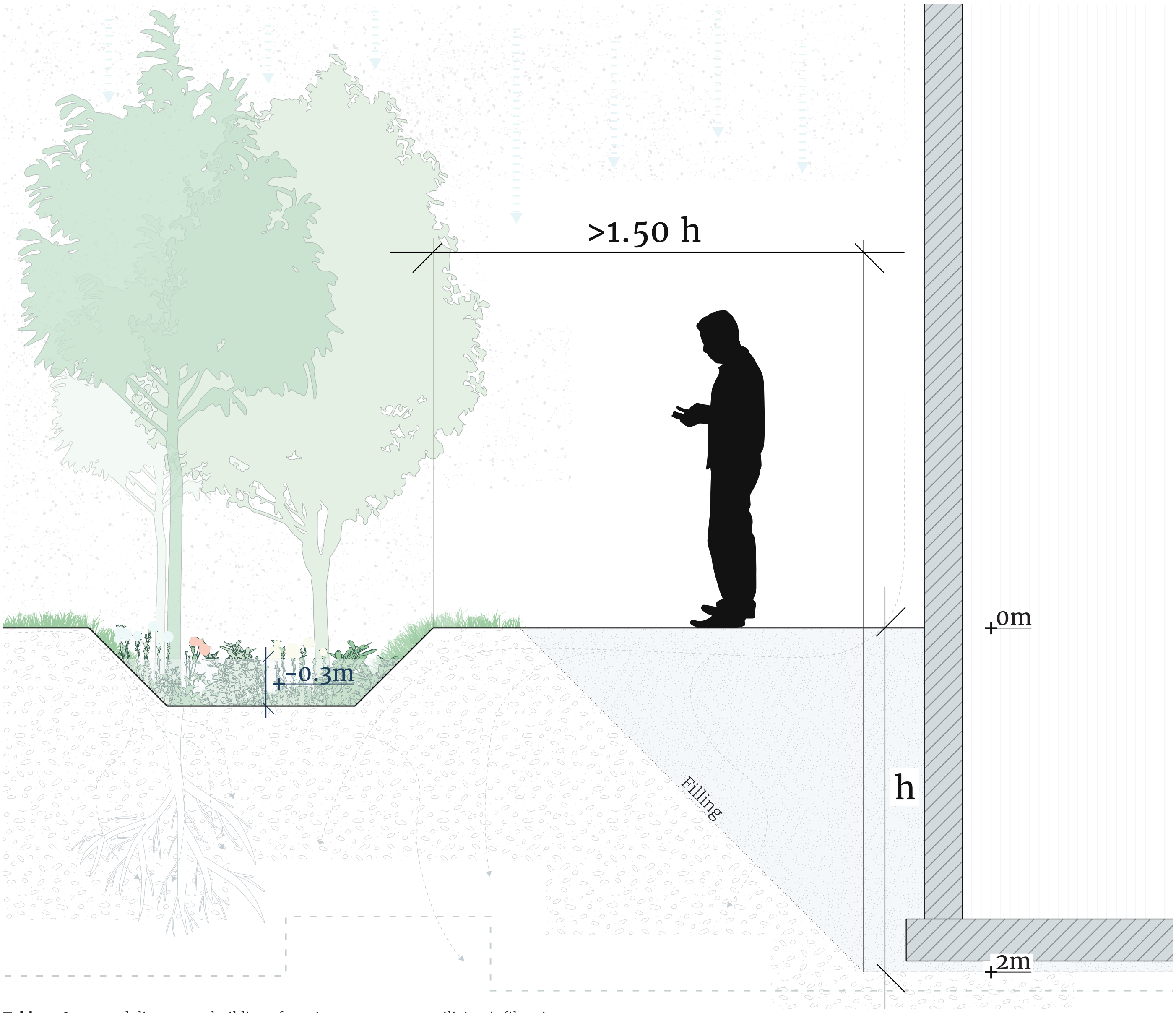


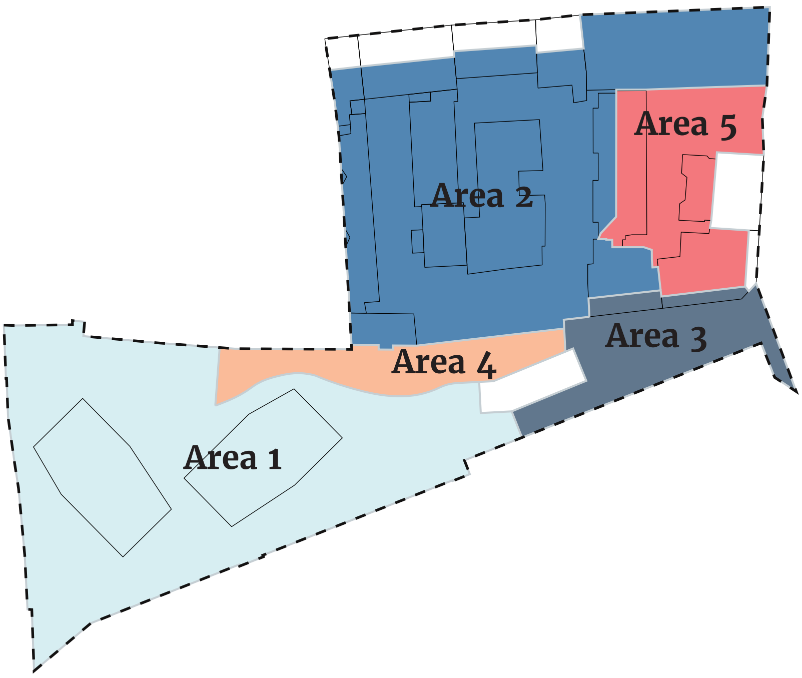
Table 7: Suggested distance to buildings for rainwater systems utilizing infiltration
Source: Based on DWA (2005)

C.8 RAINWATER FACILITIES AND THERMAL COMFORT

Facility	Notes
A1	• Green space is linked to evapotranspiration and cooling of surrounding areas (Jansson et al., 2007); • Trees can be placed
A2	• Higher soil-moisture (compared to impermeable pavement) improves evaporation; Effect on thermal comfort better for pavements with integrated vegetation (Li et al., 2013) • Higher root absorbing area and better evapotranspiration from trees, compared to impermeable pavements; Effects not as good as on natural ground (Fini et al., 2017) • Trees need proper planning to be installed, otherwise destruction of pavement possible due to root growth (Balder et al., 2018)
A3	• Green areas cool through evapotranspiration (Jansson et al., 2007) • Water is stored for short periods of time (DWA, 2005), though its positive cooling effects on thermal comfort may be lessened by an increase in air humidity (Teshnehdel et al., 2022) • Extra availability of water can up to double the growth of trees (Grey et al., 2018)
A4	• Green areas cool through evapotranspiration (Jansson et al., 2007) • Water is stored for short periods of time (DWA, 2005), though its positive cooling effects on thermal comfort may be lessened by an increase in air humidity (Teshnehdel et al., 2022) • The amount of water received is much higher compared to A3 (DWA, 2005); Extra availability of water is positive for tree growth, however, proper positioning of trees in the facility is necessary to prevent harm from waterlogging (Grey et al., 2018)
A5/B5	• Water is stored subsurface (DWA, 2005), leading to no specific effect on thermal comfort for the facility itself • Surface area above can be used for programming
A6/B6	• Green areas cool through evapotranspiration (Jansson et al., 2007) • Water is stored for short periods of time (DWA, 2005), though its positive cooling effects on thermal comfort may be lessened by an increase in air humidity (Teshnehdel et al., 2022) • Special technical adaptations can be made to keep water stored underground for vegetation and trees to be available throughout prolonged dry periods (Pallasch et al., 2016) • Possible drainage prevents waterlogging in slow infiltrating soils (ibid.) • Improves evapotranspiration of vegetation (ibid.)
A7/B7	• Similar to A6/B6 on a technical level • Green areas cool through evapotranspiration (Jansson et al., 2007) • Water is stored for short periods of time (DWA, 2005), though its positive cooling effects on thermal comfort may be lessened by an increase in air humidity (Teshnehdel et al., 2022) • Special technical adaptations can be made to keep water stored underground for vegetation and trees to be available throughout prolonged dry periods (Pallasch et al., 2016) • Possible drainage prevents waterlogging in slow infiltrating soils (ibid.) • Improves evapotranspiration of vegetation (ibid.)
A8	• Water is stored subsurface (DWA, 2005), leading to no specific effect on thermal comfort for the facility itself • Surface area above can be used for programming
A9	• Can be build with concrete, or earth formed (DWA, 2005), allowing flat vegetation and evapotranspiration (Jansson et al., 2007) • Basins are water-sealed to adjacent soil (DWA, 2013), allowing no deep roots and trees • When designed as a constant waterbody, temperatures of surrounding areas are reduced (Teshnehdel et al., 2022)
A10	• While surrounding temperatures are reduced through evapotranspiration, the effect on thermal comfort decreases with its height above ground (Pfoser & Jenner, 2014; Perini & Magliocco, 2014) • Improves cooling load of buildings, reducing its energy-demand/output (Pfoser & Jenner, 2014)
S1	• Effectively decreases temperatures at pedestrian levels by up to 1,3 C° through evapotranspiration (Wong et al., 2010) • Shown better cooling effects on pedestrians than green roofs (Perini & Magliocco, 2014)
S2	• Water is harvested in tanks (DIN, 2022), leading to no specific effect on thermal comfort for the facility itself • Surface area above can be used for programming • Modern systems utilized harvested water to automatically water vegetation/trees (Nichols & Lucke, 2015) • Use for gardening leads to green space and evapotranspiration (Jansson et al., 2007)

Table 8: Notes for the derivation of the microclimate-score for various rainwater-management systems

APPENDIX D HYDRAULIC PERFORMANCE CALCULATION



Ill. 1: Separation of the site in 5 sub-catchment areas

$$A_U = \sum A_{E,i} * \Psi_{,m,i}$$

Factors (DWA, 2005: 21)		0,75	0,9	0,5	0,1	1,0	
Catchment	**Area $A_{E,i}$ [m²]**	**Area $A_{E,pavement}$ [m²]**	**Area $A_{E,roof}$ [m²]**	**Area $A_{E,green\ roof}$ [m²]**	**Area $A_{E,green\ area}$ [m²]**	**Area $A_{E,rain\ facility}$ [m²]**	**Unsealed Surface A_U [ha]**
1	3280	1840	0	760	440	240	0,20
2	3220	980	1360	630	150	100	0,24
3	670	530	90	0	10	40	0,05
4	480	380	0	0	70	30	0,03
5	840	390	410	0	0	40	0,07

Table 1: Calculation of the unpaved area for each catchment

A9 – Rain Basin 1

$$V = (r_{D,n} * A_U - Q_{DR,1}) * D * f_Z * 0{,}06$$

A9 – Rain Basin 2

$$V = (r_{D\,n} * A_U - Q_{DR,2} + Q_{DR,1}) * D * f_Z * 0{,}06$$

Q_{DR} Controlled discharge [l/s]

$Q_{DR,2}$ 5,5 l/s

$Q_{DR,1}$ 2 l/s

A4 – Infiltration Basin

$$v_{f,u} = \frac{k_f}{2} * l_{hy} = \frac{k_f}{2} * \frac{h_s + z}{h_s + \frac{z}{2}}$$

$$Q_S = v_{f,u} * A_S$$

$$Q_{S,mid} = \frac{Q_{S,max} + Q_{S,min}}{2}$$

$$Q_{DR} = \frac{A_U * q_{dr,k}}{1000}$$

$$V = (A_U * 10^{-3} * r_{D,n} - Q_{S,mid} + 10^{-3} * Q_{DR,2} - Q_{DR}) * D * 60 * f_Z$$

$Q_{S,mid}$ Average infiltration [m³/s]

$v_{f,u}$ DARCY's Law

l_{hy} Hydraulic gradient

A_S 40 m²

k_f 0,00005

h_s 7,2 m

$q_{dr\,k}$ 10 l/(s*ha)

z_{min} 0 m

z_{max} 1 m

A6 – Infiltration Trench
B6 – Infiltration Trench (with discharge)

$$V_M = (A_U * 10^{-7} * r_{D,n} - A_S * \frac{k_f}{2}) * D * 60 * f_Z$$

$$S_{RR} = \frac{S_R}{b_R * h_R} * [b_R * h_R + \frac{\pi * d^2}{4} * (\frac{1}{S_R} - 1)]$$

$$Q_{DR} = \frac{A_U * q_{dr,k}}{1000}$$

$$l_R = \frac{A_U * 10^{-7} * r_{D,n} - Q_{DR} - \frac{V_M}{D * 60 * f_Z}}{\frac{b_R * h_R * S_{RR}}{D * 60 * f_Z} + (b_R + \frac{h_R}{2}) * \frac{k_f}{2}}$$

Formula can be used to adjust sizing/dimensioning between grass swale and infiltration chamber

$$V_R = l_R * h_R * b_R * S_R$$

l_R Length of infiltration chamber

S_{RR} Total storage coefficient

V_M Grass Swale Volume
(A6) 3,6 m³
(B6) 9,0 m³

A_S (A6) 25 m²
(B6) 40 m²

$b_M = b_R$ Width of systems: 2m

d 0,2 m

h_R Height of infiltration chamber: 0,66 m

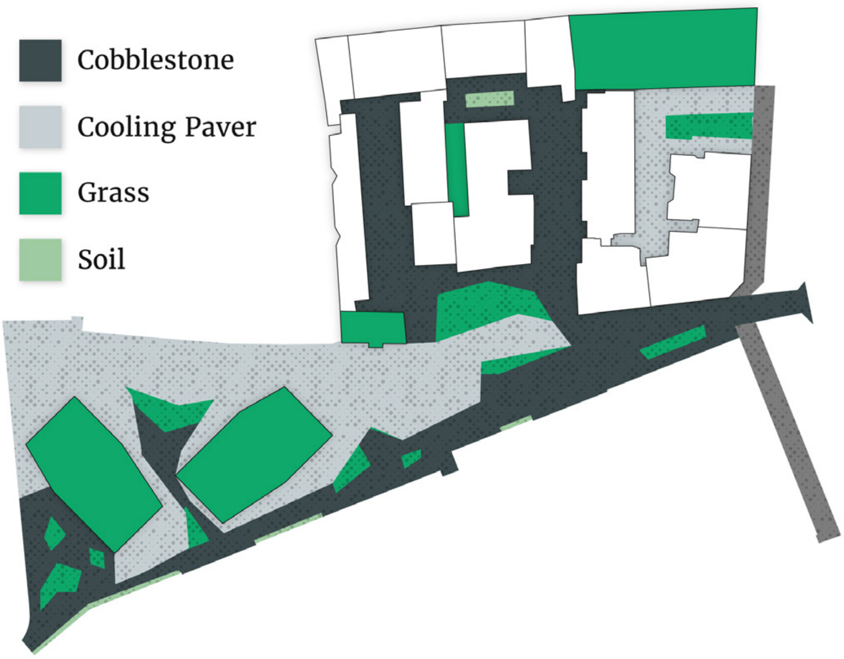
k_f (A6) 0,00005
(B6) 0,000000

$q_{dr,k}$ (A6) 0 l/(s*ha)
(B6) 10 l/(s*ha)

S_R 0,95

APPENDIX E MATERIALS USED

Ill. 1: Starting point Materials for thermal comfort simulation



Ill. 2: Post-design Materials used in simulation 2 of the outdoor comfort simulation