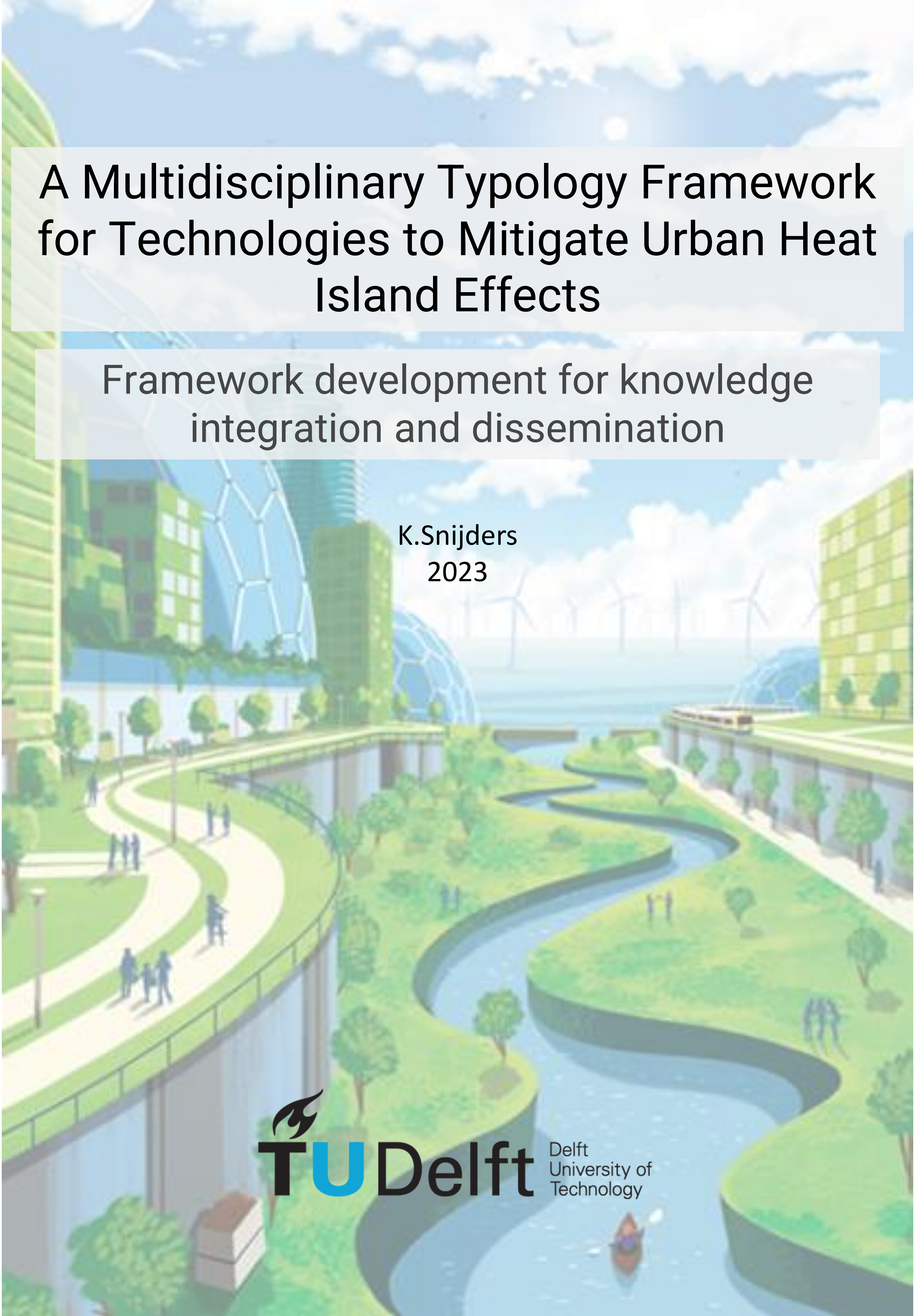
A Multidisciplinary Typology Framework for Technologies to Mitigate Urban Heat Island Effects

Framework development for knowledge integration and dissemination

K.Snijders

2023



Delft University of Technology

MSc Thesis Environmental Engineering

A Multidisciplinary Typology Framework for Technologies to Mitigate Urban Heat Island Effects

Framework development for knowledge integration and dissemination

Kevin Snijders

August 2023

Assessment committee:	Dr. Ir. M.M. Rutten (Chair)
	Dr. ir. J.E.Goncalves
	Ir. E. Stache
Date of Submission:	September 2023
Faculty:	Faculty of Civil Engineering
	Delft University of Technology
Master:	Environmental Engineering

Preface

This report presents the findings of my master's thesis research, titled "A Multidisciplinary Typology Framework for Mitigating Urban Heat Island Effects," conducted from February to September 2023 as part of my Master's degree program in Environmental Engineering at Delft University of Technology.

Throughout this research, I had the privilege of collaborating with professionals from various fields, enriching my perspective as a future engineer. This experience significantly influenced both the research itself and my overall approach. Conducting this study challenged me in ways that expanded my knowledge and revealed my strengths and weaknesses, contributing to my personal and professional growth.

I extend my gratitude to the diverse group of individuals I interacted with during this research journey, including fellow students, researchers, designers, municipal representatives, innovation developers, architects, entrepreneurs, legal experts, consultants, and more. Special thanks are due to the following individuals:

- Dr. Ir. M.M. Rutten, my main supervisor, for her continuous support, fruitful discussions, and the freedom she provided to tailor the research to my preferences.
- Dr. Ir. J.G. Goncalves for her valuable perspectives on Urban Design, which challenged my civil engineering background and enriched the research.
- Ir. E. Stache, for her inviting me to participate in expert integration sessions that inspired this research, and willingness to be interviewed, contributing to the research results.
- Floor Pino, for her responsiveness, support, and the opportunity to conduct a workshop during one of The Green Village's events, which greatly benefited the research.
- Esmee Kaldenhoven and Daniel van der Riet for their peer review and critical feedback, helping me enhance the quality of this work.

Kevin Snijders
Delft, 13 September 2023

Abstract

Urban areas often experience temperature imbalances, resulting in higher temperatures than their rural surroundings, known as the Urban Heat Island (UHI) effect. This effect has adverse consequences such as heightened heat-related morbidity and mortality, amplified energy demands, aggravated water scarcity, and diminished urban living comfort. These effects are expected to intensify due to urbanisation, making cities more susceptible to heat-related problems and increasing the number of inhabitants subjected to them, and climate change, increasing the frequency and intensity of heat waves occurring. As more than half of the world population lives in these urban areas, the imperative for effective mitigation strategies becomes paramount.

Addressing the complexity of the urban environment necessitates the collaboration of various disciplines to create effective UHI mitigation strategies. However, the integration and dissemination of multidisciplinary knowledge in this context are currently inadequate. This study bridges this gap by introducing a multidisciplinary typology-based framework employing a concurrent mixed-method approach, encompassing systematic literature reviews, semi-structured expert interviews, and multidisciplinary workshops in four distinct phases. These phases are specifically designed to identify, collect, integrate, and disseminate knowledge in this field, with applicability across diverse disciplines and contexts.

While the framework was first designed for the technologies at "Heat Square" of "The Green Village" in Delft, Netherlands, it is highly adaptable and can accommodate the inclusion of different technologies to enhance its impact. Given the increasing importance of addressing UHI challenges, this framework contributes to integrating and disseminating knowledge, supporting the creation of mitigation strategies and, therefore, contributing to creating livable and resilient urban environments in response to a changing climate.

Keywords

- Urban Heat Island Effect
- UHI Effect Mitigation Technologies
- Multidisciplinary Typology
- Knowledge Integration

Contents

List of Figures

List of Tables

Nomenclature

HREC Human Research Ethics Committee . . . 20
LCZ Local Climate Zone . . . 10
PCIS Permavoid Capillair Irrigation System . . . 32
TGV The Green Village . . . 3
TU Technical University . . . 26
UHI Urban Heat Island . . . 1

1 Introduction

Urban areas, encompassing towns, cities, and metropolises, play an essential role in accommodating human populations. Globally, these regions constitute less than 2% of the Earth's total land area, yet they provide a home for more than half of the global populace, a number that continues to grow [Ritchie and Roser, 2018; Lai et al., 2019]. By the year 2050, projections indicate that 68% of the world's total population will live in urban areas [UN Habitat, 2022]. The interplay between people and the urban environment, intensified by this momentum, thus sets the stage for current and future human habitation. The Netherlands mirrors this global trend, with a substantial 74% of its population currently residing in urban settings [Nabielek and Hamers, 2015].

In parallel with this urbanisation trend, causing the transformation of sparsely populated open-country or rural areas into dense concentrations of people [Ritchie and Roser, 2018], climate research projects an escalation in the frequency and intensity of heat waves occurring in the Netherlands [Attema et al., 2014] and predicts this as one of the most significant risks for living conditions in urban areas [IPCC, 2022]. Furthermore, the specific characteristics of urban areas render them particularly susceptible to the aggravation of heat-related challenges [Russo et al., 2015; Klok and Kluck, 2018; Meehl and Tebaldi, 2004]. This susceptibility is rooted in their morphology, activities, and distinctive attributes [EEA, 2020], collectively contributing to significantly heightened temperatures compared to rural environments [Stewart and Oke, 2012; Rizwan et al., 2008]. This phenomenon is commonly called the Urban Heat Island (UHI) effect and is visualised in Figure 1.1. While this effect has been under study for several decades, it only gained significant attention in the Dutch context after 2009 [Echevarría Icaza et al., 2016; Garssen et al., 2005]. However, as urbanization and climate change trends converge in Dutch cities, the thermal stress burden amplifies, underscoring the imperatives to gain knowledge in this field.

Moreover, adverse consequences of this phenomenon are evidenced across societal dimensions, including heightened heat-related health risks, amplified energy demands, aggravated water scarcities, and diminished urban living comfort [Klok and Kluck, 2018; IPCC, 2022; Heaviside et al., 2017; Chakraborty et al., 2019]. Consequently, as urbanization and climate change trajectories converge, adapting urban areas to these escalating heat effects becomes paramount to creating livable urban environments for present and future generations. Therefore, the imperative for effective mitigation strategies gains prominence.

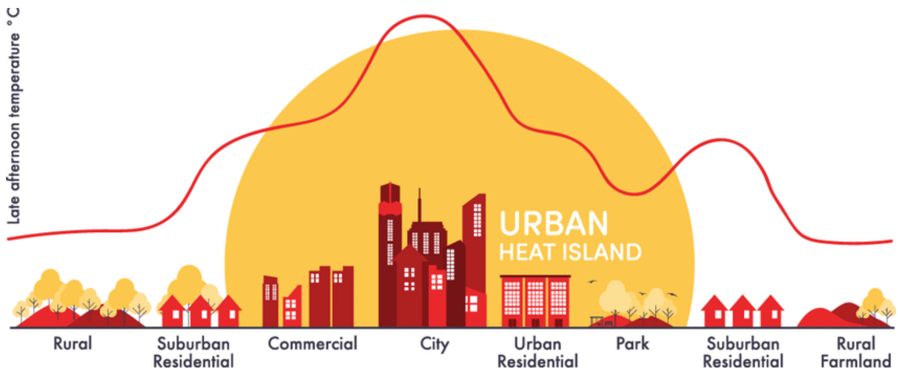


Figure 1.1: Visual Depiction of Urban Heat Island (UHI) Effect. The vertical axis of the illustration depicts late afternoon temperatures in degrees Celsius, while the horizontal axis distinguishes various environmental settings. Adapted Fuladlu et al. [2018], retrieved on August 10, 2023.

1.1. Urban Heat Island Effect

The UHI phenomenon, characterised by elevated temperatures in urban areas compared to the rural surroundings, has captivated scientific and societal interest for decades. Coined by Balchin and Pye in 1947, this effect embodies the intersection of challenges arising from urbanisation and climate change [Stewart and Oke, 2012]. The underlying factors contributing to this phenomenon are [Aleksandrowicz et al., 2017; Santamouris and Kolokotsa, 2016; Peng et al., 2021; Dirksen et al., 2019; EPA, 2022; Kleerekoper et al., 2012] (Figure 1.2):

1. Short-wave solar radiation is absorbed by low-albedo materials and trapped by multiple reflections between buildings.
2. Urban air pollution absorbs and re-emits long-wave radiation.
3. Sky obstruction by buildings reduces long-wave heat loss from streets, causing heat to be absorbed and re-radiated within the urban area.
4. Anthropogenic heat emissions.
5. Abundance of materials encompassing large heat storage capacity and thermal admittance such as concrete and brick.
6. Urban areas experience reduced evaporation due to impermeable surfaces and limited vegetation, resulting in more sensible heat and less latent heat.
7. Wind speed reduction decreases turbulent heat transport within streets.

Despite the increasing understanding of the phenomenon and its origin, a systematic literature review uncovers gaps in knowledge that impede a comprehensive approach to mitigating the UHI effect. Foremost among these gaps is the absence of integration and dissemination of multidisciplinary knowledge across the diverse disciplines within this field [Alcoforado et al., 2009; Aleksandrowicz et al., 2017; Oliveira et al., 2020]. As articulated by Ortman et al. [2020], the urban environment is highly complex as it forms "a biological environment, a social environment, a built environment, a market environment, a business environment, and a political environment", which are all interconnected. Resolving problems in such an environment, i.e. UHI effect mitigation, requires combining a broad range of expertise and understanding - both

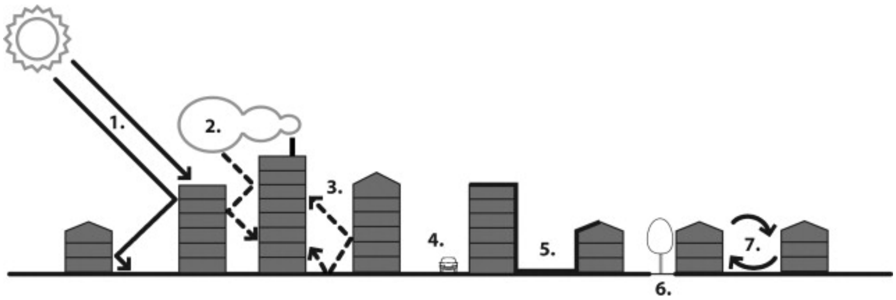


Figure 1.2: Visual Depiction of Urban Heat Island (UHI) Effect contributors corresponding to the provided list. Adapted Kleerekoper et al. [2012], retrieved on August 22, 2023.

scientific and non-scientific - depending on the involvement of various stakeholders [Lawrence et al., 2022; Lang et al., 2012]. However, the transfer and integration of this knowledge remains challenging due to conflicting definitions [Cortes Arevalo et al., 2023], the lack of discipline connection [Lee and Kim, 2022; Akbari et al., 2016], profession silo thinking [Lähde and Di Marino, 2019], and required expertise to understand and use specific knowledge [Eliasson, 2000]. The latter is evident, for example, when urban planners may lack the expertise to grasp all urban regulations, whilst juridical experts possess this knowledge but lack expertise in urban planning. Given the complexity of the urban environment, both aspects are indispensable, highlighting the essential need for knowledge integration and transfer [Bosch et al., 2013; Lee and Kim, 2022; Akbari et al., 2016; Eliasson, 2000]. Previous endeavours to offer comprehensive tools to these parties have proven infeasible due to the prerequisite for specialised expertise and incomplete discipline involvement, which leads to a lack of comprehensiveness [Wang et al., 2021; Butt and Dimitrijević, 2022; Cortes Arevalo et al., 2023].

Furthermore, trends in UHI effect research identified by Aleksandrowicz et al. [2017], Mohammad Harmay and Choi [2022], and Geng et al. [2023] underscore an observable positive association between climatological attributes, the magnitude of UHI effects, and the extent of research output. This leads to an inclination for research activities to be more concentrated in regions characterised by more frequent occurrences of heatwaves and heightened UHI effects. Notably, this pattern is evident in the United States, China and Australia. However, these studies concurrently point to the constrained generalizability of their findings across varied climatic contexts. Consequently, the broader application of these research outcomes is limited. This constraint, in combination with the stated lack of research output before 2009, causes a lack of UHI effect research focused on the Dutch urban context [Echevarría Icaza et al., 2016; Garssen et al., 2005].

Lastly, UHI mitigation research predominantly concentrates on a narrow range of techniques, such as reducing solar radiation absorption, enhancing airflow, and implementing vegetation-based solutions [Deilami et al., 2018; Rehan, 2016; Giguère, 2009]. Alternative strategies, like modifying urban envelope characteristics, incorporating water bodies, and altering material thermal properties, receive less attention, as argued by [Aleksandrowicz et al., 2017] and [Santamouris and Kolokotsa, 2016]. Moreover, they conclude that focusing on individual mitigation technologies overshadows comprehensive, integrated design approaches. Appendix C of this report presents a detailed justification of these knowledge gaps.

An initiative to contribute to UHI effect mitigation knowledge is the The Green Village (TGV) at the Delft University of Technology in the Netherlands. One of their designated research sites, the "Heat Square", investigates UHI mitigation solutions through innovative technologies [TGV, 2023]. Throughout this research, the Heat Square is transformed into a "Cool Square", integrating nine technologies in an integral design. This initiative aims to comprehensively study individual components, synergy effects, and the overall impact of the design, quantitatively assessing effects and qualitatively understanding cooling mechanisms. Its goal is to gain UHI effect mitigation knowledge, enhance the implementation of mitigation technologies and bolster the capability to combat UHI effects.

Within TGV, diverse disciplines converge and collaborate, including designers, technology innovators, researchers, residents, and more. This convergence, coupled with the context of the Netherlands and the incorporation of a range of mitigation technologies within an integral design, renders the Heat Square a case study for this research, as further expounded upon in Chapter 3.

1.2. Problem statement & Research question

Arising from the presented knowledge gaps, the central problem statement to this research is defined as follows: "Leading trends within UHI mitigation research shows an inclination towards a specific set of mitigation pathways and with that unilaterally developing the knowledge within this field. This, combined with research activities being limited to a single mitigation technology, neglects potential synergies and hinders effective implementation scenarios. Moreover, current research fails to integrate and distribute their knowledge multidisciplinary and harnesses limited applicability due to the result's dependence on climatological characteristics. Overall, these trends significantly impede advancing the field of UHI mitigation and implementing effective solutions".

This research focuses on multidisciplinary knowledge integration with a contribution to the climatological and technological claims by considering the integral Heatsquare design of TGV. It aims to develop a framework to identify, gather, integrate and disseminate this knowledge systematically. Supporting this objective, the central research question is stated below. A crucial aspect of this question revolves around "multidisciplinary typology", defined as "a systematic categorisation that integrates insights and knowledge from multiple disciplines to identify essential informational aspects required for the urban implementation of technologies. This classification aims to help organise and structure complex information, making it easier to understand, analyse, and apply. In assessing and implementing innovative technology, a typology could involve categorising different aspects or components of the technology, such as its features, functionalities, potential benefits, risks, implementation strategies, user requirements, and more. Creating a typology serves the purpose of assisting both researchers and practitioners in gaining a comprehensive understanding of the technology's nuances, diversities, and implications, thus enabling well-informed decision-making throughout the evaluation and implementation phases".

Research Question

"How can Urban Heat Island mitigation knowledge be gathered, described and distributed comprehensively using multidisciplinary typology?"

Due to insufficient research on innovative technologies for UHI effect mitigation, integrating knowledge about these technologies becomes challenging. Addressing this issue, the initial step of this research involves formulating a hypothesis outlining the qualitative cooling mechanisms of these technologies. This encompasses hypotheses from both technological and design perspectives, aligning with the scope of the case study conducted in this research. The pursuit of addressing the subsequent sub-question, which is constructed from two distinct components, is aimed to provide this knowledge.

Subquestion 1 *What are the hypotheses regarding UHI effect mitigation of the implemented technologies on the Heat Square at TGV?*

A What are the cooling hypotheses[1] of the integral Heat Square design at TGV?

B What are the cooling hypotheses [2] of the individual technologies implemented in the Heat Square design at TGV?

To comprehensively integrate multidisciplinary knowledge, it is essential to identify and outline diverse disciplines engaged in UHI effect mitigation. This is pursued through the formulation of the research question presented below. Additionally, the resolution of this sub-question facilitates the identification of disciplines that warrant consultation for developing a multidisciplinary typology, a prerequisite for the ensuing inquiries as later elaborated on in Chapter 4.

Subquestion 2 *Which disciplines are involved with urban development processes?*

Given the pivotal role of the multidisciplinary typology within the main research question, the pursuit of comprehensiveness of this typology is essential. To support that goal, as well as to assess each method's feasibility and reliability in the overarching framework that is being developed, both scientific and non-scientific sources are consulted. To do so, the subsequent research question comprises two individual queries, each tailored to a separate approach.

Subquestion 3 *How can the key aspects for UHI effect mitigation technologies be defined utilizing multidisciplinary typology?*

A What are the typologies used to describe UHI effect mitigation innovations in the scientific literature?

B What are the typologies used to describe UHI effect mitigation innovation in the field practical implementation?

To satisfy the core research objective, the following sub-question is proposed to provide insight into the intended knowledge integration and dissemination across multiple disciplines involved in the field of UHI effect mitigation.

Subquestion 4 *How can UHI effect mitigation knowledge be presented comprehensively suited for multidisciplinary integration and dissemination?*

[1]Referring to the qualitative mechanism of UHI effect mitigation

This research aims to develop a framework to gather and disseminate UHI mitigation knowledge. The key steps include understanding the cooling mechanisms of various technologies, identifying information for urban implementation using multidisciplinary typology, and creating an initial visual representation of an information interface. The scope of this research encompasses a set of nine technologies relevant to UHI mitigation currently tested at TGV (Chapter 3). Data will be gathered and analysed for five of the nine selected technologies. Subsequently, one specific technology will undergo comprehensive result processing to develop and execute the informative and practical framework. The data gathered for the remaining technologies will serve as a valuable foundation for future framework execution and expansion. This framework aims to set new standards for collecting and presenting UHI mitigation knowledge with multidisciplinary applicability, contributing to creating livable urban environments for present and future generations.

1.3. Report outline

In the text above, the subject of this research is introduced, the objective is described, the relevance is elaborated, and the research questions are presented.

The second chapter, Chapter 2 *Theory - UHI Effect Mitigation*, of this report elaborates on the theory behind UHI mitigation, which supports the understanding of the research findings and this report in general.

Chapter 3 *Case Study - Heat Square at The Green Village* presents the scope of this research and introduces the case study conducted in this research. This will be done respectively, in two distinct sections.

Chapter 4 *Methodology* describes the applied methodology. This chapter is composed of four sections elaborating on the specific research strategies applied to each stated subquestion.

The fifth chapter, Chapter 5 *Results*, presents the research outcomes for each stated research question.

Chapter 6 *Discussion* firstly recapitulate the key research results of each methodology approach and elaborate on its implications. Next, it is discussed how these individual results contribute to the overarching framework. The implications of this framework are elaborated on within the scope of the research area and in a broader perspective. Furthermore, this chapter presents the identified research limitations and expands on the recommendations for further research.

Lastly, this report finalises with the concluding chapter presented in Chapter 7. This chapter concludes on the stated subquestions, expands on the conclusion that can be drawn from a broader research context, and ends with an overarching concluding statement.

2
Theory - UHI Effect Mitigation

To support the understanding of this research, a theoretical background on UHI effect mitigation is provided in this chapter. However, this knowledge is not required to conduct the developed framework, which is designed to be adaptable to any field, regardless of prior knowledge on UHI effect mitigation. Therefore, the theory presented in this chapter supports the developed framework rather than being a part of it as elaborated n in Chapter 4 Figure 4.1.

2.1. Theory

The UHI effect arises from the radiation imbalance between incoming and outgoing energy in urban areas. The absorbed radiation (Q_A $[W/m^2]$) is the difference between the total incoming solar radiation ($Q_{i\downarrow}$ $[W/m^2]$) and the reflected portion, which depends on the surface albedo (r [-]), as shown in Equation 2.1. The absorbed energy can be converted into different forms, including conventional heat (Q_H $[W/m^2]$), heat storage change (Q_C $[W/m^2]$), longwave radiation (Q_R $[W/m^2]$), or latent heat (Q_E $[W/m^2]$), based on the illuminated surface characteristics, as described in Equation 2.2 This partitioning of absorbed energy is a simplified model based on the first law of thermodynamics and does not consider terms such as advection or anthropogenic heat. However, to understand mitigation pathways, this simplified model provides adequate knowledge.

$$Q_A = (1 - r)Q_{i\downarrow} \tag{2.1}$$

$$Q_A = Q_H + Q_C + Q_R + Q_E \tag{2.2}$$

Based on the equations mentioned above, mitigation of UHI effect can be achieved by reducing the amount of absorbed heat (Q_A), which can be accomplished by increasing the portion of reflected radiation or by redirecting the absorbed energy into forms that have minimal impact on creating a UHI effect being latent heat. Increasing the albedo (r [-]) of urban surfaces, hence reducing the absorbed portion of incoming radiation, is a numerous documented and frequently applied approach to mitigate UHI effects. However, its applicability depends on the design limitation and the local urban morphology. Especially the latter, alteration in albedo could result in the incoming radiation being reflected between elements of the built area, trapping the energy rather than reflecting it into the higher atmosphere. Additionally, as direct contact with solar radiation is one of the significant contributors to the experience of thermal discomfort to the human body and heat stress, this "echoing" of radiation could expose urban inhabitants to even more heat [Salcedo Rahola et al., 2009; Lee et al., 2014; Cheng et al., 2012], albeit its absence within the design.

On the other hand, research performed by Hoelscher et al. [2016] and Rizwan et al. [2008] concludes that the occurrence of an UHI is predominantly correlated to the portion of absorbed energy converted to convectional heat at the urban surface. Hence, the reduction of this fraction would contribute to reducing the effect. Convective (sensible) heat transfer (Q_H) is driven by a temperature gradient between the material surface and its directly surrounding atmosphere and is facilitated by the movement of air [Oke, 1988; Bergman et al., 2017]. A greater temperature gradient equals a greater fraction of absorbed energy converted to convective (sensible) heat.

The term Q_C represents conductive heat transfer, referring to the heat transferred through the material mass [Oke, 1988]. Energy stored in the material contributes to convectional heat transfer to the surroundings, known as re-radiation when the air temperature falls below the material temperature. Materials with high conductivity warm the urban canopy layer, amplifying nocturnal temperature and hindering cooling when the air temperature drops [Rizwan et al., 2008].

The thermal longwave radiation term (Q_R) is determined by the difference between the incoming and outgoing longwave radiation [Bergman et al., 2017]. The outgoing longwave radiation of a material, driven by the temperature gradient between the material and its surroundings, is dependent on the thermal emissivity [1] of the material. It is a pathway to which a material loses radiative energy accompanied by a reduction in temperature. However, outgoing longwave radiation can be re-absorbed by other materials and, with that, be transformed into convectional heat, thereby contributing to the UHI phenomenon [Kwon and Lee, 2019].

The last component of the absorbed radiation is the radiation converted to latent heat. This energy pathway is defined as the required energy causing a phase change at constant temperature and pressure [Hall, 2010]. For the context of the UHI mitigation, this phase change refers to liquid water being evaporated and extracting energy (temperature) from its surroundings to break the molecular bonds. This energy pathway is referred to as latent heat (Q_E) and results from the evaporation of water or the transpiration by vegetation. As the latent heat can leave the urban canopy layer [2] in the form of water vapour, energy stored within this vapour is 'lost' and therefore contributes to mitigating the UHI effect [Ottelé and Perini, 2017].

As the urban morphology of the research area cannot be changed, e.g. surrounding buildings cannot be removed nor can their orientation be altered, and the increase of reflected radiation is deemed non-ideal, guiding the absorbed energy into the most favourable energy form is deemed most applicable. As supported by researchers Stache et al. [2022], minimizing absorbed energy being transferred into convective heat and maximizing the conversion into latent heat is presumed to be the most effective mitigation pathway and, therefore, central to this design. In essence, the design revolves around transforming the absorbed heat into latent heat as much as possible and generating micro-circulations that effectively allow the water vapour to leave the urban canopy layer. The presented theoretical framework herein provides a solid foundation for the comprehensive interpretation of the results elucidated in Section 5.1 of Chapter 5, allowing to effectively address the primary subquestion posited at the outset of this study.

[1] The temperature emissivity of a material refers to its ability to emit thermal radiation relative to that of an ideal black body at the same temperature. In other words, it measures how efficiently a material radiates heat compared to a perfect emitter, known as a black body [Barreira et al., 2021].

[2] The urban canopy layer refers to the layer of vegetation, buildings, and other structures in urban areas, often found in cities and towns. It is analogous to the canopy layer in natural ecosystems, but in an urban context, it includes artificial elements as well as vegetation Oke [1988].

3
Case Study - Heat Square at The Green Village

In this chapter, the study's scope and the applied case study within this research will be presented. In Section 3.1, the constraints of this research will be elaborated upon with regard to its development and intended deliverables. Furthermore, in Section 3.2, the applied case study within this research will be introduced, offering insight into this area and the integrated UHI effect mitigation technologies, which define the boundaries for the remainder of this report.

3.1. Research Scope

Emphasis on the research deliverables provides insight into how the central research objective is to be satisfied. First and foremost, the developed framework, elaborated upon in Chapter 4, stands as an independent outcome that contributes to the study's objectives. The essence of this framework lies in its capacity for unrestricted applicability in the domain of UHI effect mitigation, fostering multidisciplinary connection and efficient knowledge integration and dissemination. Moreover, the individual components comprising this framework should also be recognized as research deliverables, with each element independently supporting the overarching framework. Nevertheless, it is important to acknowledge that this research operates within certain constraints despite its intended unrestricted nature.

The imposed constraints on this research have delimited the scope of technological innovations encompassed and fully executed within the framework. Accordingly, the focus is directed towards the area of interest known as the "Heat Square" situated within the premises of TGV. A comprehensive account of this area and the integrated innovations is provided in Section 3.2 of this chapter.

Furthermore, the research employs varying degrees of framework execution for these innovations. The phases "UHI Effect Mitigation Hypotheses" (Section 4.1) and "Urban Design Framework" (Section 4.2) operate without constraints. However, for the subsequent phase, "Typology for UHI Effect Mitigation Technologies" (Section 4.3), it is applied to five out of the total nine innovations in the research area, as outlined in Section 3.2. Complete framework execution, including "Interface Conceptualization" (Section 4.4), is exclusively implemented for one of the technologies. This strategic approach is designed to rigorously test the framework under limited time availability while also demonstrating its adaptability for broader applications across various technologies.

3.2. Research Area & Integrated Technologies

The present study centres on the transformed design of the "Heat Square" situated at TGV on the campus of Delft University of Technology (Netherlands). This facility utilizes a semi-controlled environment designed to mimic real-life urban settings to perform analyses on among others UHI effect mitigation [TGV, 2022]. Through this setup, research performed at this facility benefits from loosened (urban) regulations yet harvesting the input of important 'in-field' factors such as climate, weather and resident activities.

Research focusing on understanding the UHI phenomenon and aiming to couple innovative technologies within a mitigation strategy is executed at the Heat Square [TGV, 2023]. This area is designed to mimic urban settings vulnerable to thermal imbalances on which a monitoring campaign in the summer months of 2022 quantitatively concluded the effects on this square in terms of air temperature and surface temperature [Mao, 2022]. For the purpose of investigating effective methods to mitigate UHI effects and enable urban environments to adapt to predicted climate trajectories, the Heat Square is transformed into a "Cool Square" integrating nine leading-edge technologies following a synergistic design. Furthermore, the square is equipped with extensive measuring appliances, allowing for a thorough investigation of the individual incorporated components as well as the overall effect of the design.

The original version of the Heat Square was a rectangular open space comprising impervious concrete stelcon plates, which had an area of approximately 520 square meters. The area is bordered by a water body to the north, low-rise buildings (3-5m high) to the east and west, and some low vegetation on the west and north sides of the square. Following the framework developed by Stewart and Oke [2012], which allows for the classification of urban areas into different Local Climate Zone (LCZ), the original area is categorized as LCZ 6 DEG, defined as an open arrangement of low-rise buildings (1-3 stories) with an abundance of pervious land cover (low plants, scattered trees) and wood, brick, tile, and concrete construction materials. Additionally, the overarching climatic zone of Delft is classified as an oceanic climate (Cfb) according to the Koppen-Greiger framework [Kottek et al., 2006]. A visual representation of the initial state of this square is presented in Figure 3.1.

In contrast to the previous design, a new design has been developed to actively mitigate the adverse effects of UHI in accordance with the "Nature-based urban building standard" manifest, which was formulated during the EURO21 conference "Ecological and nature inclusive design of the climate resilient city" [EURO2021 and Delft, 2021]. This design integrates nine innovative technologies hypothesized to contribute to the mitigation of heat. An overview of these pathways is presented in Table 3.1, where the final column refers to the location identification in the actual design as presented in Figure 3.2. Furthermore, as previously indicated, the subset of technologies excluded from the framework execution is represented in grey within this table. For all remaining technologies, the framework is executed partially, except for the "Boomveer" technology, which undergoes the full framework implementation.

It is noteworthy that the innovation "Permeable substrate" is applied to all areas highlighted with the orange colour, but is more intensively researched on the ID location 3. Furthermore, all areas to the left of the primary middle path (ID 5, right) are covered with roof garden substrate, while all areas to the right are covered with the local substrate present in the research area. Finally, the design's limitations arise from the existing functionality of the space as well as the already established morphology of the adjacent domain. The transformation of the square has been initiated simultaneously with this research and was completed in August 2023.

(a) Top View of the 'Heat Square' at The Green Village (Delft, the Netherlands). Adopted from Google maps (2018) retrieved February 2023.

(b) Personal Perspective of the 'Heat Square' at The Green Village (Delft, the Netherlands). This photograph captures the researcher's subjective impression of the 'Heat Square'. Adopted from Google maps (2018) retrieved February 2023

Figure 3.1: Overview of old Heat Square design at The Green Village (Delft, Netherlands)

Table 3.1: Overview of Technologies Implemented at the New 'Heat Square' Design at The Green Village, Delft. Grey-coloured rows indicate technologies implemented within the design but not specifically focused on within the scope of this research. The term 'nd' refers to 'not defined' as the location of this innovation is yet to be determined during the development of this report (August 2023). Information was obtained from privately shared documents by The Green Village (TGV).

Innovation	**Innovator**	**Location ID**
Bluebloqs Loop	Field factors	1
ZOAK Pavement	Tilysystems	2
Permeable substrate	Koers	3
Permavoid Capillair Irrigation Systems	New Urban Standard	2, 3, 4D
Boomveer	Urban Jungle	7
Grass length	Koninklijke van Ginkel Groep	4
Temperature gradient 'Het Briesje'	Department of Material & Environment faculty of Civil Engineering TU Delft	5
Urban rainshell DSI/EWB infiltration well	Urban rainshell & O2DIT	6
Populieren	Ebben	nd

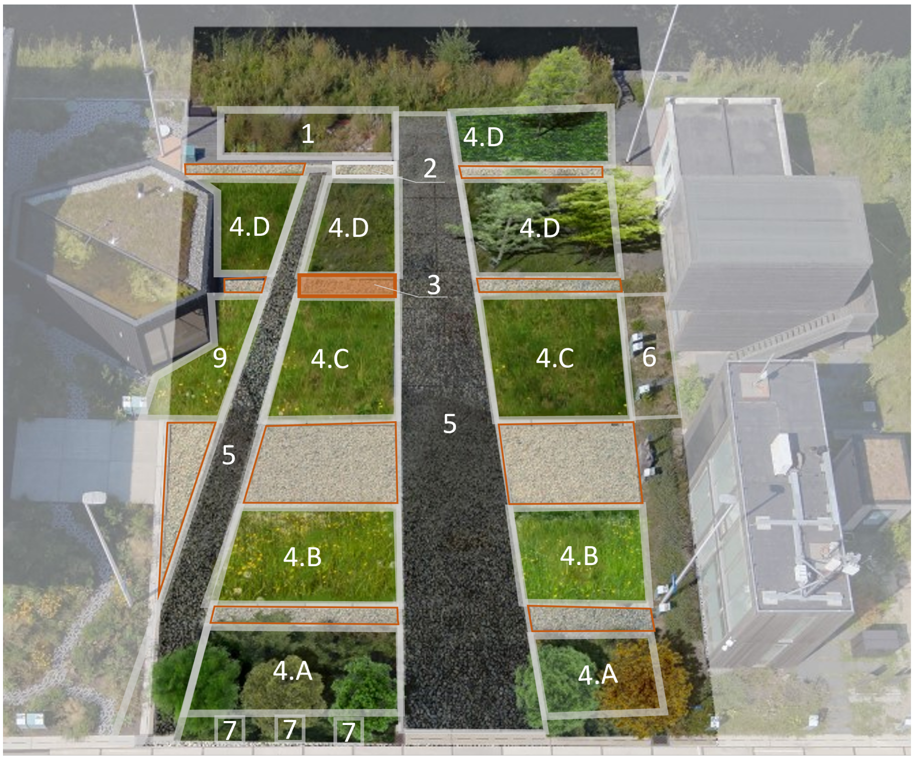


Figure 3.2: Overview of the Integrated Technologies at the New Heat Square Design. The location identification numbers correspond to those in Table 3.1. The orange-coloured area indicates the specific testing site for Koers' permeable substrate, while the orange-outlined areas represent research areas where the same material is implemented but not the primary focus (enabling synergy research with other innovations). Letters A, B, C, and D denote different grass-mowing regimes: A - Never mowed, B - 4 times per growing season, C - 10 times per growing season, and D - 25 times per growing season. Adapted from a privately shared document by E. Stache and modified by the author. Date of retrieval: 04/03/2023.

4
Methodology

This chapter outlines the approach and methods to achieve the study's objective. The methodology is structured into four distinct phases, each producing separate research outcomes but collectively from a systematic framework, which is also one of the outcomes of this research. This framework employs a mixed-method approach to identify, gather, integrate, and disseminate knowledge related to mitigation UHI effects.

A schematic representation of this framework is presented in Figure 4.1 to facilitate a visual grasp of the concept. This illustrative diagram delineates the interconnections among the distinct phases while highlighting the methodologies employed and the research outcomes accomplished within each phase. The diagram employs colour coordination for phase identification and arrows to signify the links between phases. Accompanying call-out boxes, also colour-matched, provide a textual description, elaborating how the findings from one phase contribute to the subsequent connected phase. As discussed previously, it is noteworthy that the theory regarding UHI effect mitigation (Chapter 2) is intentionally situated outside the framework. This placement reflects its role as supportive rather than obligatory for the framework's execution. Although this research commenced with this theory, the framework initiates at a different phase and follows the numerical sequence depicted in the flow diagram.

The upcoming paragraphs describe methods and approaches conducted in the framework of each phase individually.

4.1. UHI Effect Mitigation Hypotheses

The framework is initiated by developing an understanding of how technologies aid to mitigate the UHI effect. This understanding supports the aim for knowledge integration of (new) technologies, especially ones that are yet to be described in the literature. For established and proven technologies, literature could be consulted for this objective. However, literature and performance reports are yet to be conducted or openly available for newer technologies, such as those focussed on within this research. Therefore, independent of the maturity of the technology, this understanding is gained by collecting the hypotheses via in-person semi-structured interviews with a technology representative and supplemented with the information presented at the innovations website if available. For accuracy purposes, the acquired knowledge is cross-verified with the interviewee(s) during the report-writing stage of this research.

Essentially, this approach is applicable to gain a comprehensive understanding of any technology in general. However, in line with the scope of this research, this is only performed for the selected technologies incorporated within the Heat Square as described in Chapter 3.

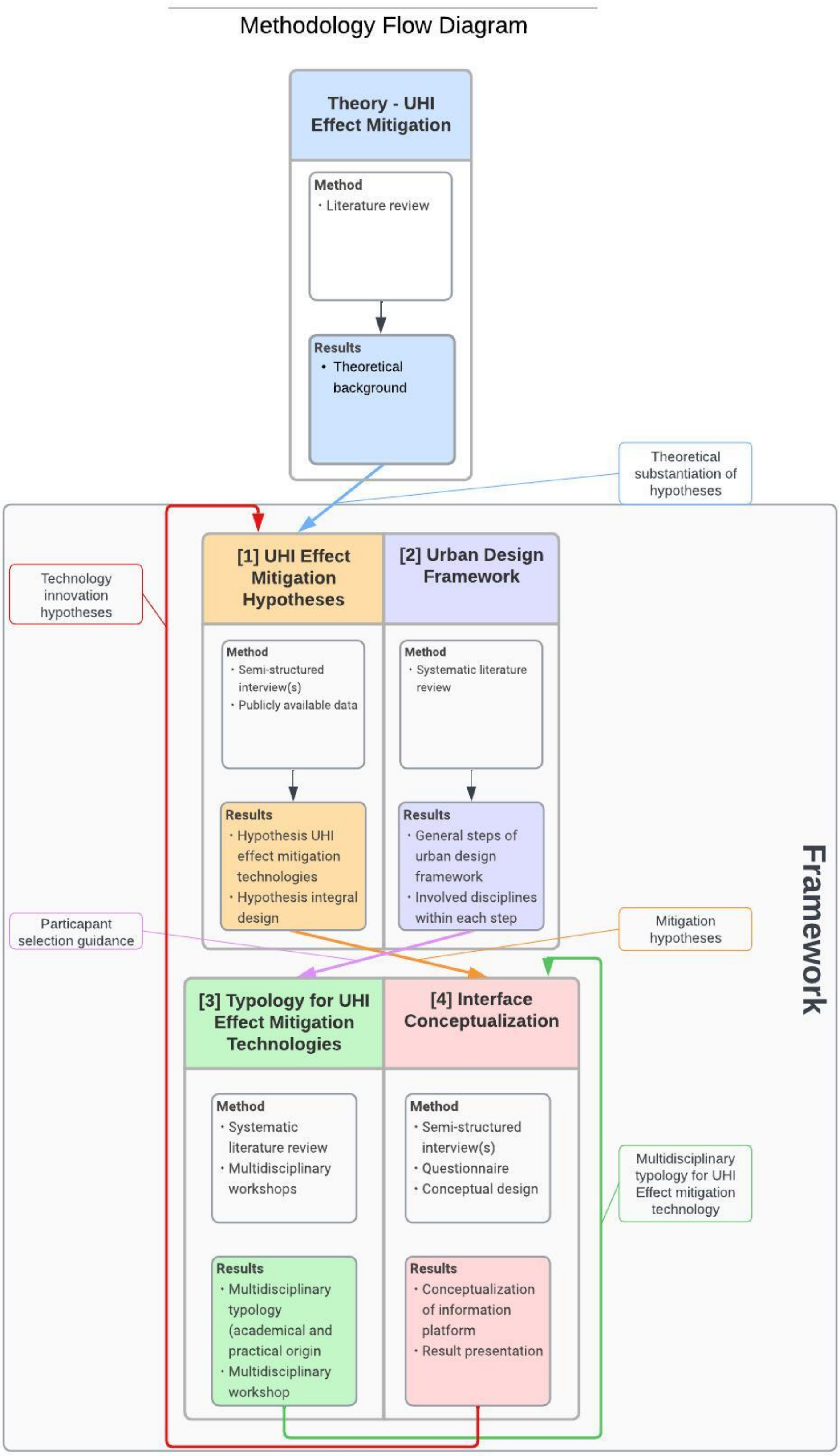


Figure 4.1: Illustration of the Methodology Flow Diagram, providing a comprehensive depiction of the employed methods, the devised framework, and the interconnectedness between various methodological stages. The diagram should be interpreted sequentially from top to bottom, with the numerical labels denoting the progression of framework phases. The coloured arrows indicate the propagation of outcomes from distinct methodology phases, facilitating their incorporation into subsequent stages.

Consequently, a slight alteration of the methodology was conducted where a technology representative and the responsible designer of the Heat Square were interviewed. For the latter, lead designer, architect, and researcher E. Stache, who in collaboration with TGV developed the design of the Heat Square, was consulted (interview, April 3, 2023)(interview transcript available on request). Hypotheses statements at the individual technology level were provided by Stache and supplemented with the gained information from interviews with the technology representative performed at the final phase of the framework (Red arrow in Figure 4.1). As an integral design is focused on within this research, this approach is adjusted to acquire knowledge on an individual technology and integral design level in parallel. Ultimately, it contributes to the understanding UHI effect mitigation technologies substantiating succeeding framework phases as visualized by the orange arrow in Figure 4.1.

4.2. Urban Design Framework

Aiming to describe the urban design framework, focusing on which phases are generally conducted within the urban design process and which disciplines are involved within each phase, a literature review approach was carried out. This review aims to address the second sub-research question, contributing to the overall understanding of the urban implementation process and guiding participant selection for the succeeding framework phase (purple arrow in Figure 4.1). Given the objectives of this review, which prioritize comprehensiveness, reliability, and reproducibility while avoiding favouritism towards a (set of) discipline(s), a systematic literature review approach is considered most appropriate. This method reduces the potential for bias compared to more traditional approaches, such as narrative reviews [Bryman, 2012].

4.2.1. Data Selection, Processing and Analysis

The conducted search query, as depicted in Figure 4.2 (a), was applied to three widely acknowledged open-source literature databases, Scopus, Google Scholar and Web of Science, to ensure comprehensive coverage of relevant literature. As no specific criteria regarding the document type were mandated, peer-reviewed articles, conference papers, project presentations, and book chapters were included. The search was restricted to published results within the last decade to ensure scientific relevance yet fit the length of projects within this field of interest. Furthermore, the results were ranked by relevance, putting the most cited documents on top. Additional selection options were applied for Scopus and Web of Science, limiting the search to the title, abstract, and keywords. This approach led to over 88000 results. However, as the focus of this method phase targets the description of the urban design framework and identification of the involved disciplines rather than conducting a comprehensive literature review, the top fifty most relevant articles from each platform were selected, resulting in an included data set of 150 articles for analysis. Although the determining factors for relevance for each platform could show deviation, they all refer to the same principles described by Spärck Jones [1972]. As the precise determination of relevance across the platforms is unknown, each platform's 50 most relevant results have been interpreted as equally relevant. An overview of this search, accompanied by the number of results per database, is depicted in Figure 4.2(a).

The analysis of the articles followed a systematic process. Initially, each article's titles, abstracts, and keywords were scanned to assess their relevance in addressing the targeted objective. Articles that did not adhere to this criterion were excluded. From the initial 150 articles focusing on the design phases of urban planning, only 34 articles were deemed suitable for full-text screening. Secondly, articles were either included based on their relevance to the research during the full-text screening phase or excluded. Additionally, this phase utilised "snowball sampling", where references and citations within the selected articles were used to find new relevant articles [Goodman, 1961]. This approach led to the inclusion of 17 articles selected for full-text analysis. The latter was conducted utilizing ATLAS.ti Scientific Software Development GmbH [2023] software, facilitating content analysis via manual coding. Each article was individually coded based on which phases were conducted within its described urban design framework and which key disciplines, actors or stakeholders were involved.

4.3. Typology for UHI Effect Mitigation Technologies

To satisfy the core objective of this research and close the existing knowledge gap between disciplines within the field of UHI effect mitigation endeavours, an approach is required that: acknowledges the unity of knowledge, i.e. disciplines are not isolated, but rather, they contribute to a deeper understanding when studied in relation to one another [Lawrence et al., 2022]; includes multiple disciplines connected to the problem (both scientific and non-scientific) [Cortes Arevalo et al., 2023; Lang et al., 2012; Lawrence et al., 2022]; deploys co-production of knowledge [Lähde and Di Marino, 2019]; and is independent from any particular discipline in its deployment or understanding of its outcomes [Butt and Dimitrijević, 2022]. To this end, a concurrent mixed-method approach utilizing multidisciplinary typology [1] is deployed, which is further elaborated on in this paragraph.

Concurrent Mixed-Method Approach

By adopting a concurrent mixed-methods approach in this study, data is collected through distinct methodologies to address the same research question [Mabry et al., 2008]. This research employs a systematic literature review and multidisciplinary workshops conducted in parallel. This dual-method strategy serves two key purposes: data expansion, which involves enriching the depth and breadth of outcomes beyond what each method could achieve independently [Hall, 2020], and corroboration, wherein the results obtained from one method are authenticated by those of another [Campbell and Fiske, 1959]. Notably, the data processing protocols for both approaches are uniform, enabling a comprehensive analysis of inconsistencies and discrepancies between the methods Hall [2020].

Furthermore, due to the experimental nature of implementing a multidisciplinary typology (detailed in the subsequent section), it is recommended to cross-reference the outcomes with a reference method, i.e., the literature review. This practice validates results and provides an alternative data source if the experimental method fails to achieve its objectives [Mabry et al., 2008]. By adopting such an approach, not only are the research outcomes reinforced in terms of robustness, but it also facilitates an assessment of the individual effectiveness and feasibility of each distinct method.

[1] defined as "a systematic categorization that integrates insights and knowledge from multiple disciplines to identify essential informational aspects required for the urban implementation of technologies. This classification aims to help organize and structure complex information, making it easier to understand, analyze, and apply. In assessing and implementing innovative technology, a typology could involve categorizing different aspects or components of the technology, such as its features, functionalities, potential benefits, risks, implementation strategies, user requirements, and more. Creating a typology serves the purpose of assisting both researchers and practitioners in gaining a comprehensive understanding of the technology's nuances, diversities, and implications, thus enabling well-informed decision-making throughout the evaluation and implementation phases"

Multidisciplinarity

The utilization of the multidisciplinary typology as a data format within this methodology is exploratory due to the absence of any reported research employing this specific data format up to August 2023.

The term "Multidisciplinary" denotes collaboration among diverse disciplines, each operating within their unique domains of expertise and context. These disciplines contribute to overarching findings by sharing insights upon completing their research pursuits [Lawrence et al., 2022; Thompson et al., 2017; Nguyen and Mougenot, 2022]. Unlike transdisciplinary collaboration methods, the multidisciplinary approach does not foster close interconnections or collaborative result generation among disciplines. Consequently, this approach prioritizes simplicity, benefiting from the challenges associated with transdisciplinary collaboration, such as time constraints and difficulties in cross-disciplinary communication due to specialized terminology and expertise Cortes Arevalo et al. [2023]. This simplicity is achieved without compromising comprehensiveness, assuming relevant disciplines engage and contribute knowledge rooted in their expertise during result generation.

Typology

In the context of this research, typology is defined as "a systematic categorization to identify essential informational aspects required for the urban implementation of technologies. This classification aims to help organize and structure complex information, making it easier to understand, analyze, and apply. In assessing and implementing innovative technology, a typology could involve categorizing different aspects or components of the technology, such as its features, functionalities, potential benefits, risks, implementation strategies, user requirements, and more. Creating a typology serves the purpose of assisting both researchers and practitioners in gaining a comprehensive understanding of the technology's nuances, diversities, and implications, thus enabling well-informed decision-making throughout the evaluation and implementation phases".

The use of typology within this research derived from several "integration sessions" attended from January to March 2023 within the study "handbook on designing with/for vital soils in urban areas - the case of Westblaak, Rotterdam" conducted by PosadMawwan. In these collaborative sessions, experts from diverse fields, including soil science, hydrology, ecology, landscape architecture, and urban planning, convened for in-person meetings. The objective was to harness their collective expertise on various research components, seamlessly integrating knowledge across all stages of the design process and ensuring social and environmental equity in developed solutions [PosadMaxwan, 2023].

Collecting expert knowledge unfolded with the moderator presenting a research element and soliciting input from all participating experts in the session. This dynamic led to collaborative discussions and expert insights on the given subject. However, as an attendee of these sessions, it became evident that this process was somewhat inefficient. The inefficiency did not stem from the inability of experts to offer the required information but rather from a lack of clarity regarding the specific information sought. Only through extended discussion could the moderators pinpoint the relatively straightforward answers to their queries. Furthermore, the insights shared by the experts often delved into considerable detail, while the moderators were primarily seeking high-level information, such as the maintenance costs of a particular technology.

In essence, a disparity between formulating information requests and providing corresponding answers emerged, impeding the efficiency of the integration sessions and prolonging their duration. As a solution, the application of a multidisciplinary typology as a data format has been embraced in this research. This format enables diverse disciplines to articulate requested information while facilitating experts in supplying that information without necessitating time-intensive interactions. Central to the effectiveness of this approach is a clear and universally understandable definition of the typology, ensuring coherence among all involved stakeholders [Butt and Dimitrijević, 2022].

Overall, a typology serves as a valuable tool for organizing and presenting information coherently and structured, helping stakeholders grasp the diverse dimensions of technologies and providing guidance for decision-making and planning. This format requires no prior expertise, maintains neutrality towards any specific discipline, emerges collectively from participating disciplines, is adaptable to scientific and non-scientific contexts, and can be reproduced. Consequently, it meets the primary criteria outlined by various authorsHall [2020]; Butt and Dimitrijević [2022]; Lawrence et al. [2022]; Lähde and Di Marino [2019] and Cortes Arevalo et al. [2023] for multidisciplinary collaborative methods. Further details regarding this data format and the corresponding data collection procedure are expounded upon in Section 4.3.2.

The subsequent paragraphs elaborate on each approach, expanding their unique characteristics and processes. A data processing procedure is then applied to the acquired data from the literature review and the multidisciplinary workshops. Required outcomes from preceding framework phases and integration of the results acquired in this phase are depicted in Figure 4.1.

4.3.1. Literature Review

This approach aimed to consult academic sources and gather relevant literature on the definition of information aspects related to implementing UHI mitigating technologies. Similar to the method described in "Urban Design Framework" (see Section 4.2), a systematic literature review was initiated by performing the search query displayed in Figure 4.2(b) to the databases of Scopus, Google Scholar and Web of Science. The same inclusion criteria regarding document type, publication date and relevance level were applied to this search. Ultimately, over 39000 yielded from this search, which is not feasible to study in depth nor fitting to the scope of this research. Therefore, only the 50 most relevant articles of each data platform were included for further analysis. Ordering the results on relevance is default within Google Scholar, whilst optional for Scopus and Web of Science. Although the determining factors for relevance for each platform could show deviation, they all refer to the same principles described by Spärck Jones [1972]. As the precise determination of relevance across the platforms is unknown, each platform's 50 most relevant results have been interpreted as equally relevant.

The analysis of the included literature followed a systematic process. Initially, each article's titles, abstracts, and keywords were evaluated for their relevance in addressing the method objective. Articles that did not directly contribute to this were excluded. A total of 81 articles were included for full-text screening. During this phase, articles were either included based on their relevance to the research or excluded. The "snowball sampling" technique was also employed, utilizing references and citations within the selected articles to find additional relevant sources [Goodman, 1961]. As a result, nine articles were included for the information aspect typology.

These articles were thoroughly read and analyzed using the ATLAS.ti Scientific Software Development GmbH [2023] software.

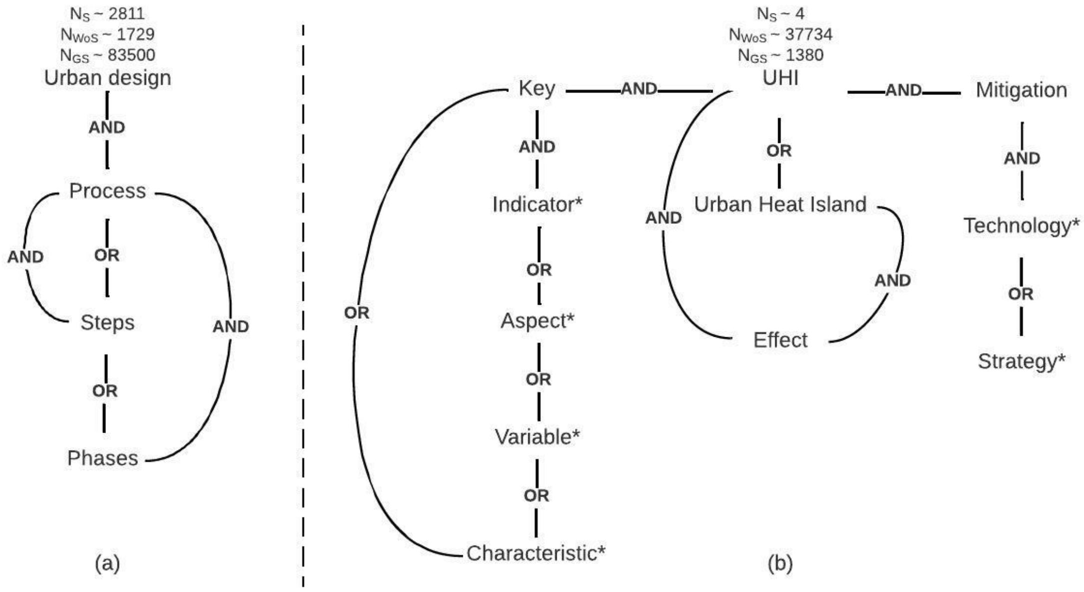


Figure 4.2: Representation of the Search Term Overview for (a) the literature review focused on the Urban Design Framework, and (b) the literature review for the Typology of UHI Effect Mitigation Technologies (current as of August 2023). The presence of "OR" signifies the inclusion of synonymous terms in both searches. Topics linked by "AND" denote separate search queries. Using asterisks (*) implies flexibility in character grouping for a more extensive search. "N" represents the total outcomes retrieved from the consulted database, as indicated by the subscript notation.

4.3.2. Multidisciplinary Workshop

Per the advocated approach that acknowledges the complexity of the central topic, the methodology involved consulting scientific and non-scientific sources [Butt and Dimitrijević, 2022]. To account for the latter, co-creation "Multidisciplinary Workshop" sessions were developed, involving representatives from various disciplines engaged in the field of UHI effect mitigation. Identifying these disciplines was purposed to be informed by the urban design framework literature review conducted within the previous framework phase. However, analysis of the results (Section 5.2) revealed the absence of an established standardized framework encompassing a specific set of disciplines for the implementation of UHI mitigation strategies within urban areas. Instead, the involved disciplines proved to be highly context-specific, ranging from architects, urban planners, policymakers, government officials, consultants, and legal experts to technology developers. Consequently, the selection procedure for incorporating participants in the workshops was arbitrary. Nevertheless, a diverse range of included disciplines was pursued to ensure data comprehensiveness.

Workshop development

The development of the workshop was performed iteratively. First of all, the format of a collaborative workshop session was inspired by attended knowledge integration sessions at TGV

("Rotterdams Weerwoord", February 23 2023) and PosadMaxwan ("handbook on designing with-/for vital soils in urban areas", February 28 2023). These sessions conducted multidisciplinary workshops, referring to the process where participants from various disciplines collaboratively think about solutions to an introduced problem from their specific expertise as a format to generate results. The participants of these sessions and the moderators are identified as the audience of this research but, more importantly, prospective end-users of the products developed by this research. Therefore, the fact that these sessions were conducted in this way gave rise to consulting this format for the objectives of this research.

The workshop's development was iterative, drawing initial inspiration from collaborative workshop sessions attended at TGV ("Rotterdams Weerwoord" on February 23, 2023) and Posad-Maxwan ("handbook on designing with/for vital soils in urban areas" on February 28, 2023). These sessions involved multidisciplinary workshops, where participants from various fields collectively addressed problems using their specific expertise. This format was adapted for this research due to the similarity in intended participants.

The primary objective of the developed workshops is to generate a comprehensive list of information aspects used to describe the requisite information for the assessment and implementation of innovative UHI mitigation technologies. An iterative process, allowing for improvement based on collected participant feedback, was utilized to develop this workshop. Flexibility in the workshop execution was developed to account for varying prerequisites of the workshop setting in terms of duration, material availability and participant number. The following procedure presents the final form of the conducted workshop:

1. **Informed Consent**
   Participants are briefed on the research objectives and the utilization of their generated data within the study. The data generation format and processing methodology are communicated. Additionally, participants are explicitly instructed to avoid disclosing personally identifiable information in adherence to the approved ethical guidelines (Human Research Ethics Committee (HREC)). Approximately 5 minutes should be allocated to this step.

2. **Workshop Introduction & Context**
   The workshop initiation encompasses a comprehensive contextual introduction. The extent of this introduction is tailored to workshop constraints, considering both time availability and participant familiarity with the subject matter. The primary aim is to ensure participants understand the subject adequately. Thus, a description of the UHI effect problem ensues, encompassing its origins and consequential impacts. This is followed by introducing the research domain, which includes elaboration on TGV site. The conventional and new Heat Square designs are expounded. An overview of the study's incorporated innovations is provided concerning the new Heat Square design, albeit without intricate details. Subsequently, the crux of knowledge integration deficits within UHI mitigation is introduced, exemplifying potential contributing disciplines. This introduction draws upon slides [1] to [5], as outlined in the designated material list in Chapter 7.3 of this report. Approximately 10 to 15 minutes should be allocated to this step.

3. **Data Generation Explanation**
   Participants will receive detailed instructions on data generation. The following query, "What information is required about an innovation that aims to mitigate the UHI effect to implement this within the urban environment", is used for this data generation. Another framing involves prompting participants to contemplate inquiries pertinent to assessing or deploying such technologies. The participants are informed that they should write these

requisites and queries on a sticky note. This format is specifically favoured as it allows participants to articulate in a way they prefer (phrases, sketches, sentences, etc.). Simultaneously, they are informed that they can place that sticky note in one of six topic clusters. However, it is crucial to emphasize that the objective of this exercise is not data allocation but rather that these topic clusters are introduced to cultivate multidimensional thinking and stimulate a more comprehensive data generation. The facilitator will illustrate the data generation process by offering an example corresponding to each topic cluster. Slides [11] till [13] of the presented material (Appendix A) should be utilized, and approximately 10 minutes should be allocated to this step.

4. **Introduction Innovation**
One of the five innovations incorporated in this research is now fully introduced to the participants. This introduction is based on the hypotheses' results (Section 5.1.2). The core objective of this step is to give the participants a general idea of the innovation that stimulates them to think about which information is additionally needed for the assessment and implementation of this innovation. The specific technology slide in Appendix A (slides [6] up to [10]) should be used for this step. Approximately 5 to 10 minutes should be allocated to this step.

5. **Brainstorm Activity**
The participants are now instructed to start with data generation, as outlined in step [3], focusing specifically on the innovation introduced in the preceding phase. They are informed of the option to undertake this task individually or collaboratively with other participants. Additionally, they are briefed on the possibility of expanding upon existing data entries should they encounter difficulties generating novel data. To elucidate this, the example of "Costs" may be further dissected into subcategories like "Installation costs," "Energy Costs," "Maintenance costs," and so forth. A minimum duration of 20 minutes is required for this activity to facilitate a productive brainstorming session. However, this time frame can be extended, contingent upon session time constraints. For comprehensive participant guidance, an overarching slide outlining the activity's objective, the innovation's details, and visualization of the potential outcome of this activity is provided (slides [11] Appendix A). The facilitator will oversee and direct this activity, remaining available for participant inquiries.

6. **Iteration Step [4] & [5]**
If time constraints permit, workshop steps [4] and [5] can be successively employed for the remaining innovations. For each subsequent innovation, the brainstorming session can be condensed to a minimum of 10 minutes, given that numerous generated data possess a broader scope applicable to multiple innovations concurrently. Participants are directed to employ distinct coloured sticky notes for each newly introduced innovation, facilitating data-innovation correlation.

7. **Closing Statement, Feedback & Discipline Identification**
The session is concluded upon meeting time constraints or participants expressing an inability to generate data further. The session closes with an appreciative statement, acknowledging participants and reiterating the importance of their informed consent. Subsequently, participants are requested, if agreeable, to offer a broad depiction of their respective disciplines. This description should balance specificity to allocate the pertinent disciplines and generality to preclude personal identification. The facilitator will review each discipline description before collection as a precautionary measure. The session

draws to a close with an open discussion asking for constructive feedback to enhance future iterations of the workshop.

Conducted Workshops

A total of four workshops were conducted until saturation was reached. In total, twenty-two (22) participants from fourteen (14) distinct disciplines were included as depicted in Table 4.1. The saturation point of the workshop was determined as the ratio between all and unique results compared to previously gathered results and was set to 33%. This point was deemed suitable as it indicated that the workshop had adequately explored and captured the relevant information without requiring extensive time.

The iteration initiated with a preliminary session called "Testing". While the objective of this session was to test the workshop methodology, the generated results were considered equally valid compared to the subsequent workshop sessions, as the workshop was evaluated as effectively satisfying its objective and, therefore, did not undergo significant changes after that (Chapter 7.3).

Subsequently, three additional workshop sessions were conducted, each iteratively improved based on participant feedback from the previous session. This process was performed until the set saturation point was achieved. For transparency and reproducibility of this process, each workshop session has been textually documented Chapter 7.3 of this report.

Table 4.1: Composition of Disciplines in Multidisciplinary Workshops. To ensure participant anonymity, discipline descriptions are presented in a broad context, adhering to ethical considerations. The term "Ns" refers to not specified.

Profession	**Discipline**	**Number of participants**
Academic	Environmental Technology & Design - Urbanism	1
Academic	Urban Design - Climate adaptation	1
Academic	Urban planning & Design - Urban climate planning	1
Advisor Municipal Health Service	Environment and Health	1
Consultant/advisor	Green and Ecology	1
Consultant/developer	Ns	1
Entrepreneur	Climate adaptation solution in the urban environment	2
Government advisor	Climate adaptation in the urban environment	1
Landscape designer	Ns	1
Municipality director	Climate adaptation	1
Policy officer	Public space & Climate adaptation	1
Policy officer	Urban water management & Climate adaptation	1
Policy officer	Water & Climate	2
Project employee	Natural playgrounds	1
Project employee	Urban green	2
Project employee	Urban studies	1
Project leader	Urban green	1
Trainee	Urban green	1
Urban designer	Ns	1

4.3.3. Data Processing

The data processing method was applied to all typology results. A schematic representation of this procedure is presented in Figure 4.3. This data processing procedure aims to facilitate data comparison, aimed at verifying the achievement of the workshop's saturation point and comparing the typology used for information aspects in the literature with that generated by the participants in the multidisciplinary workshops.

Due to variations in the format of the collected data between the applied approaches, the initial two phases are exclusively conducted for the data obtained from the multidisciplinary workshops. Subsequently, the results are combined into a merged dataset and processed consistently with the preceding phases. This data processing procedure is visually presented in Figure 4.3 comprising of the following phases:

1. **Digitalization**: All data collected from the multidisciplinary workshops necessitated digitalization, as the raw data in the form of written 'sticky notes' was unsuitable for subsequent processing phases. This digitalization procedure was carried out manually, ensuring that all data was transcribed verbatim from its written form to the digital format to eliminate the introduction of biases.

2. **Language Formatting**: The adaptive nature of the developed workshop resulted in the workshop data being gathered in different languages (Dutch and English). The Dutch-generated data needed to be transformed into English to enable effective data comparison. This language formatting process was conducted manually, with additional support from freely available online language tools OpenAI [2023] and Rev [2023].

3. **Data Merging, Duplicate Removal & Saturation Setpoint Analysis**: This process involves consolidating all data from individual workshops into a unified dataset. This merging process is performed based on the uniqueness of the data entries of each workshop in successive order. Individual data entries from each workshop are analysed to determine whether they are identical to those of preceding workshop data entries. If such duplicates are identified, they are eliminated from further processing. The ratio between raw and unique data, referring to not identical to previously gathered data entries, allowed for direct saturation point analysis of each workshop session while reducing the workload in succeeding procedure phases. Following this process, the literature data, which does not require the first and second data processing phases due to its format, is added to the merged dataset, and any identical data entries are once again removed.

4. **Definition Assignment**: To establish clear and consistent definitions for each unique data entry, adhering to academic definition principles is paramount. These principles encompass the incorporation of three fundamental elements within each definition according to Terjesen [2007]: (1) Definiendum, representing the term requiring definition; (2) Definiens, denoting a word or phrase that elucidates or describes the defining property of the definiendum; and (3) Denota, which provides a concrete example illustrating the extension of the definiendum. It is important to acknowledge that, for this research, the inclusion of Denota in the processed data may vary depending on the specific context. To mitigate the potential introduction of human bias during the definition assignment, a freely accessible language-based tool, OpenAI [2023], is employed. This online tool is specifically instructed to follow the academic rules stated above when generating the definitions and adhering to the context of this research. By relying on this computer intelligence, the risk of human bias is minimized. This automated approach does not only significantly expedite the procedure, it notably enhances the consistency of the definition assignment process. However, it is crucial to emphasize that all definitions are manually reviewed for correctness.

5. **Synonym Identification, Removal Synonym Duplicates & Clustering**: Building upon the definitions assigned in the preceding phase, the unique data entries undergo analysis based on these definitions, leading to the identification and elimination of synonym duplicates within the dataset. This process yields a significant reduction in the number of data entries to be processed while minimizing data loss and enhancing the overall robustness and efficiency of the procedure. Given the uncertainty surrounding the tool's proficiency for this specific purpose, this analysis is done manually. Lastly, data entry definitions identified as not identical synonymic but do overlap are clustered. This clustering is done manually because no tools for clustering were identified to comply with the pursued accuracy. This procedure resulted in a total dataset of unique typology clusters.

6. **Typology Clusters Definition Assignment**: Similar to the second procedure phase, the merged typology clusters resulting from the previous step are assigned new definitions based on the definitions of its merged components. This second definition assignment procedure is carried out manually, with assistance from OpenAI [2023] to expedite the process.

7. **Topic Clustering**: In the final step, the comprehensive data set, comprising a list of typologies and their corresponding definitions, derived from merged data entries and individually assigned definitions, is clustered based on topics. The primary aim of this procedure is to present the results in a clear and organized manner. Due to the lack of available tools that perform typology clustering, this step is carried out manually.

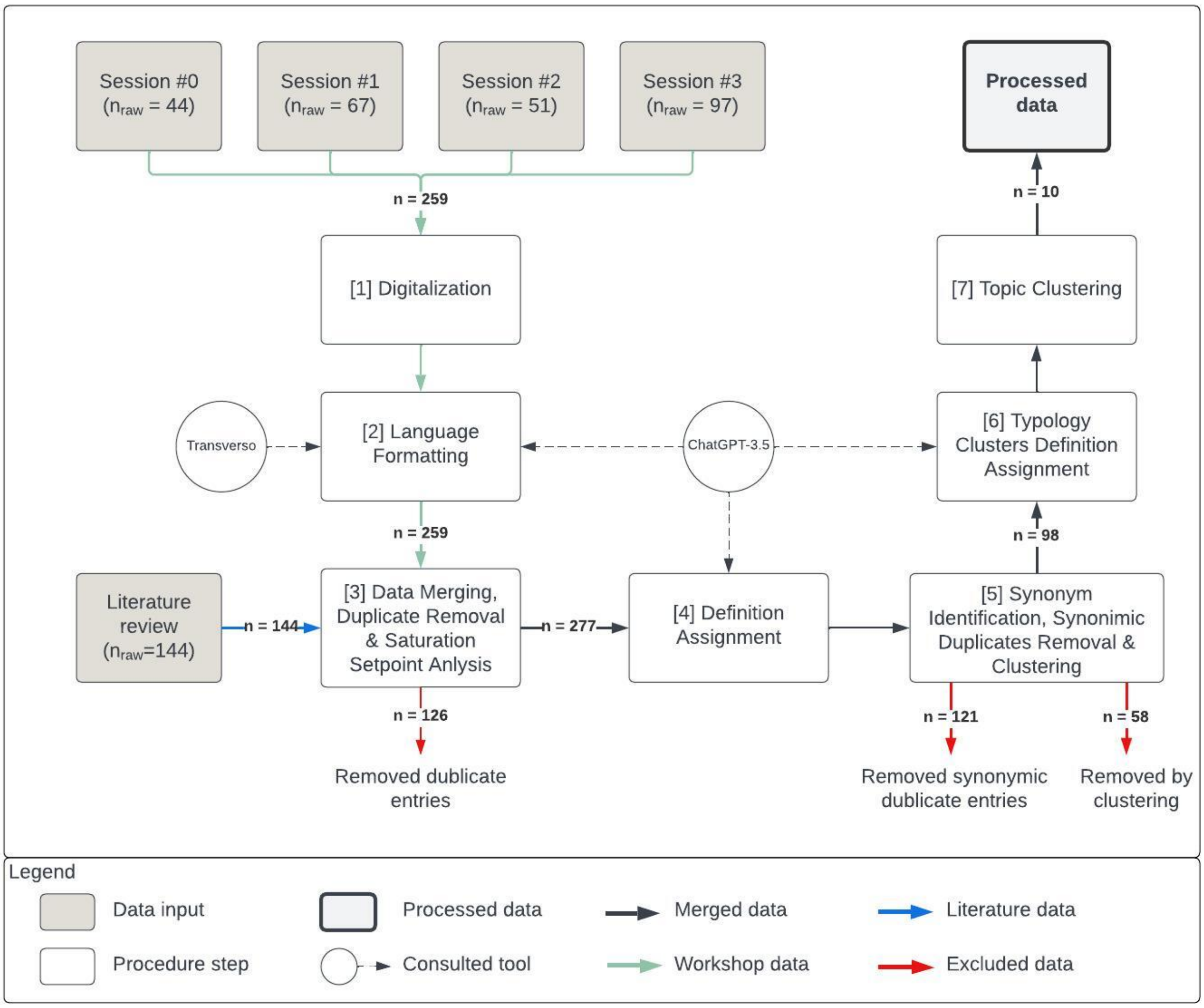


Figure 4.3: Illustration of the Data Processing Procedure. The procedure commences from the upper left corner and follows the directional arrows within the diagram. Scheme elements are elucidated in the accompanying legend. Detailed explanations of the enumerated steps are provided in Section 4.3.3

4.4. Interface Conceptualization

The last phase of the framework aimed to create a presentation format that promotes multidisciplinary knowledge integration. However, due to limitations in this research's scope, the complete development of such a format was not pursued. Therefore, this phase produced a conceptual representation of the intended interface, outlining its functionality. The next sections will detail the approach to developing this concept, the data collection and processing for its content, and the validation process.

4.4.1. Key Components for the Envisioned Interface

The key interface components are primarily derived from direct engagement with potential end-users. This engagement is integrated into the research process through the developed framework and attending the "expert integration sessions" at PosadMaxwan (integration session, February 28, 2023). This provided insights into prospective users' distinct needs, preferences, and interface requirements. In this research, the engaged prospective users are represented as follows:

- **Researchers:** This category includes researchers currently conducting studies relevant to this research and researchers interested in new research activities within the Technical University (TU) Delft and external researchers in general.
- **Innovation Developers:** Representatives from the company responsible for the Boomveer innovation tested at the Heat Square.
- **Platform Manager:** The Green Village, where the research is centred.
- **Main End-Users:** Participants of workshop sessions and integration sessions at PosadMaxwan.

Secondly, the work conducted by Cortes Arevalo et al. [2023] informed the development of the interface concept in this project. Their research focused on creating a transdisciplinary collaborative tool and engaged with a diverse group of twenty potential users from various fields. The objective was to understand the essential elements of an effective online collaborative information interface. Although the specific context of their study differed from ours (centred around the Rivercare program in the Netherlands), the principles and necessities of multidisciplinary and transdisciplinary collaboration were considered transferable. This presumption led us to incorporate their findings into our study. The key components identified by Cortes Arevalo et al. [2023] are adopted and adjusted based on the insights from the engaged end-users within this research.

An overview of the key interface components and end-user-specific requirements used for developing this concept is presented in Table 4.2 and Table 4.3, respectively.

Table 4.2: Comprehensive Overview of General Interface Requirements. This table presents the requirements for the interface concept according to intended end-users and Cortes Arevalo et al. [2023].

Components	**Description**
Simplistic presentation	The content presented at the interface should be presented at distinct levels of simplicity. The highest level (referring to the most simplistic) presents information as concise and ambiguous as possible. If available, this information links to more detailed information presented on a different content page. The detailed content page links, if possible, directly to data, literature reports, research endeavours, etc., to support information credibility.
Interface guidance	The interface contains a guidance environment where end-users can familiarize themselves with its functionality.
Easy navigation	Effortless navigation and seamless access throughout the interface are guaranteed through intuitive navigation guidance and convenient quick links between related content pages.

Table 4.3: Comprehensive Overview of Interface Requirement Specifications for Prospective Users. This table provides an overview of the interface requirement for specific end-users according to intended end-users and Cortes Arevalo et al. [2023].

User Profile	**Requirement specifications**
Researchers	User-specific requirements proposed for this end-user group are: • Open and free accessibility to the content of the interface. • Access to complete referencing of content if possible. • Overview of remaining knowledge gaps. • Overview of current and prospective research endeavours connected to the field of research. • Overview of prospective research questions. • Ability to raise new questions, leave research findings, and refer to relevant literature. • Contact information for ongoing and new research activities.

Continuation of Table 4.3	
User Profile	**Requirement specifications**
Innovation developers	User-specific requirements proposed for this end-user group are: • Password-controlled asses to the interface to allow modification of all content related to their specific innovation. • Ability to state new research initiatives and raise research questions. • Overview of which questions are predominantly raised concerning their innovation. • Overview of which content is mostly consulted by end-users regarding their specific innovation. • Overview of which technology this innovation is mostly compared to.
Platform manager	User-specific requirements proposed for this end-user group are: • Password-controlled asses for complete modification of entire tool. • Content modification alert (when a developer modifies content, the platform manager should be automatically notified). • Overview of questions related to interface functionality. • Ability to expand interface with innovations. • Receiving all end-user feedback and raised questions.
Main end-users	User-specific requirements proposed for this end-user group are: • Open and free accessibility to the content of the interface. • Access to high-level and detailed information. • Access to complete referencing of content if possible. • Ability to raise questions and provide feedback on the interface. • Ability to compare technologies.
End of Table	

4.4.2. Interface Data Collection

Data collection procedures for this interface utilized semi-structured interviews conducted with innovation representatives. The typology results from the previous framework phase were processed into a questionnaire format tailored to the selected technology by excluding typologies inapplicable to the technology of interest, i.e. load-bearing capacity does not apply to the Boomveer innovation. Subsequently, a semi-structured interview was conducted with a company representative to discuss and "answer" the information clusters relevant to the technology they represented. The term "answer" in this study refers to the process wherein the company representative furnishes comprehensive information based on the provided cluster definition resulting from previous methodology phases as portrayed in Figure 4.1. Confidential and sensitive information was deliberately not disclosed during the interviews, and the whole process was approved by the HREC of TU Delft. The interviews aimed to elicit both qualitative and quantitative information, which could be expressed as either "high-level answers" (i.e. single statements or numerical values) or "detailed answers" (textual explanations supported by references). To provide flexibility in response, participants were free to determine the level of detail they preferred to provide.

4.4.3. Interface Data Processing

The previous phase's information collected through interviews and questionnaires undergoes manual processing to shape the interface. This processing is guided by the fundamental components and pre-established criteria outlined in Section 4.4.1. The interface is centred around presenting information in alignment with the identified topics and adhering to different levels of detail as previously outlined.

4.4.4. Validation & Reflecting

The interface underwent validation with end-users, assessing its compliance with the list of requirements. The consulted actors for this validation process are (identification available on request):

- The Green Village - as potential interface manager and research area Heat Square owner.
- Researcher - research on Climate Adaptation: Relating Policy, Tools, and Measures for the Public and Private sector. This researcher is consulted to provide feedback on the interface concept in terms of a tool for climate adaptation.
- Workshop Participants - These "main end-users" will be requested to use the interface within a one-on-one (online) session to provide feedback.
- Moderator Expert Integration Session PosadMaxwan - As this integration inspired elements of research, the moderator will be requested to provide feedback on the applicability of this interface concept for the integration sessions they conducted.

The feedback obtained from this validation process is utilized for identifying areas of improvement, which will inform the recommendations outlined in Chapter 6. However, Processing this feedback for improvement of the interface falls outside the scope of this research and is not pertinent to the current study.

5
Results

This chapter unfolds the research findings corresponding to each framework phase sequentially. To enhance clarity, the section heading indicates the phase to which the presented results are attributed.

5.1. Results - UHI Effect Mitigation Hypotheses

Obtained results from the first framework phase, "UHI Effect Mitigation Hypotheses", are presented in this section. These results apply to the case study presented in Chapter 3 and have been divided into two sections. Section 5.1.1 presents the results applicable to the Heat Square design as a whole, whilst Section 5.1.2 displays the findings on an individual technology level that comprise the overall design.

5.1.1. Integral Design Hypotheses

Drawing from the data obtained during the interview with E. Stache (April 3, 2023), a classification is established to present the hypotheses regarding the mitigation of the UHI effect in the Heat square design. These classifications, referred to as "cooling pathways", are centred on processes involving evaporation, transpiration, or both, and microcirculation. As the theoretical background discussed in Chapter 2 supports the proposed hypotheses, it is advisable to consult this chapter for a deeper understanding of these research findings before proceeding.

Theory - Evaporation & Transpiration

Minimizing the absorbed radiative energy being transferred into convective heat and redirecting this into latent heat is presumed to be an effective approach to mitigate the occurrence of UHI effects. The production of latent heat fluxes can be either facilitated through evaporation, energy used for the phase change of water, or via transpiration, which is defined as the exhalation of water vapour through the stomata of vegetation [Tuzet, 2011]. The combined process of the two is often captured within the term evapotranspiration. The energy "used" for this process is stored within this water vapour and is "removed" from the area when the water vapour moves out of the urban canopy layer [1]. Stache hypothesizes all technologies incorporated within the scope of this research to contribute to this cooling pathway as presented in Table 5.1.

[1] Urban Canopy layer "The atmospheric layer depending on the roughness of the soil generated by the buildings and the canopy of the trees, with an upper limit located just above the level of the roofs of the buildings. In this layer, airflow and energy exchanges are governed by microscale processes that depend on the specific characteristics of the surface." [Arellano et al., 2018]

Theory - Microcirculation

Microcirculations of air play a crucial role in the design for mitigating UHI effects, according to Stache (interview, 3 April 2023). The human experience of heat is influenced not only by sensible heat fluxes but also by relative humidity, vapour pressure, and wind speed. Research conducted by Lee et al. [2014] and Cheng et al. [2012] emphasizes the significance of wind generation and reduction of local humidity in enhancing human cooling. Therefore, the extraction of latent heat from the targeted area and the generation of wind are considered essential aspects of the mitigation design, according to Stache.

Within the design, air pressure differences are assumed to stimulate this movement of air. Temperature gradients, resulting in warm air rising and creating local atmospheric low pressure, initiate airflow. In the design, this airflow is referred to as an "artificial breeze" and is hypothesized to be facilitated by the following three design elements.

Firstly, the colour and material composition of the central path (location ID 5) is assumed to lead to higher convective energy partitioning compared to the surrounding areas. Consequently, temperature gradients and therefore air pressure differences are expected to arise between the air above the path and the air above the surrounding areas with higher latent heat partitioning capacity. Secondly, the path's shape is hypothesized to induce temperature variations along its trajectory, with wider sections exhibiting higher surface temperatures, which will cause the air temperature directly above to be higher. This air temperature difference contributes to microcirculation along the path. Lastly, variations in grass length (location ID 4) are expected to result in different levels of latent heat partitioning. Areas with longer grass lengths are hypothesized to have greater evapotranspiration and experience lower local air temperature. These local air temperature differences again cause pressure gradients, which stimulate microcirculation. However, due to their exclusion of this innovation from the research scope, they will not be further elaborated on in the remainder of this study.

Of the five incorporated technologies of this research, the "Boomveer" (ID location 7) innovation is the only technology hypothesized to contribute to the microcirculation cooling pathway. It is hypothesized that the leaf crowns of these trees create a checkerboard-like pattern on the underlying surface, resulting in localized illuminated and shaded areas. This pattern is believed to generate temperature differences on the surface, subsequently causing air pressure variations above it, which, in turn, induce airflow. These airflows are anticipated to facilitate the removal of latent heat from the square. Moreover, the strategic positioning of these innovations (3 units within this design) is anticipated to create wind corridors tailored to enhance the design's effectiveness by actively directing wind circulation and extracting latent heat from the premises.

5.1.2. Innovation hypotheses

The following paragraphs of this section elaborate on the specific hypotheses of the integrated technologies on an individual level. The results presented in this section are finalised with a tabular overview of the technologies following the overarching cooling pathways of the Heat Square design.

BlueBloqs Loop

The BlueBloqs Loop is a modular rainwater retention system that utilizes nature-based components. By allowing for evaporation and transpiration of water from the substrate and vegetation on top of the BlueBiofilter (as shown in Figure 5.1a), it can help mitigate heat. Moreover, this system can collect, treat, and store rainwater, hypothesized to have promising synergy potential for water management and irrigation purposes within the premises of the Heat Square.

ZOAK Pavement

The ZOAK pavement (a Dutch acronym for Zeer Open Asphalt Keramiek) is hypothesized to contribute to evaporative cooling due to its composition. This pavement is made from ceramic waste products and is highly porous. Internal research conducted using climate chambers has demonstrated the pavement's ability to cool its surroundings, achieved through the evaporation of water stored in the subsurface buffer zone beneath the pavement, which can be drawn upward through capillary rise [TyleSystems, 2023]. This mechanism is hypothesized to lead to cooling if water is available in the buffer zone.

Permeable substrate

The 'Permeable substrate' produced by Koers is hypothesized to facilitate evaporative cooling within the design. The innovation consists of an open-structured composition, which ensures the supply of water and oxygen to the surface's top layer [Koers, 2023]. Similar to the ZOAK pavement innovation, this permeable substrate is hypothesized to allow for evaporative cooling under the assumption of water availability in the substrate.

Permavoid Capillair Irrigation Systems

The Permavoid Capillair Irrigation System (PCIS) developed by New Urban Standard integrates fibre columns within its strata, facilitating the capillary movement of water from subsurface water storage back to the uppermost layer [New Urban Standard, 2023]. This design feature promotes extended water retention, which can be used for evaporation and irrigation depending on its application. This system is hypothesised to enhance the evaporative cooling potential of co-existing innovations, thereby establishing a synergistic interplay. In the Heat Square context, by combining the PCIS with the ZOAK pavement and permeable substrate innovation, the cooling effect of each is hypothesized to be enhanced. The system can also be integrated with surface vegetation to improve water availability, leading to healthier plants and enhanced heat mitigation through transpiration.

(a) Image of the BlueBloqs innovation. The image shows the top layer of the innovation where vegetation is implemented. Imaged adopted from FieldFactors [2023] (retrieved at 04/08/2023

(b) Image of the Boomveer innovation tested currently (August 2023) at the Heat Square of The Green Village. Imaged adopted from TGV [2023] at the specific innovation page The Green Village's website (retrieved at 04/08/2023)

Figure 5.1: Visual representation of BlueBloqs and Boomveer innovation, tested at the new Heat Square design of The Green Village (TGV) (Delft, Netherlands)

Boomveer

The ”Boomveer,” as detailed in the work of [The Urban Jungle Project, 2023], is hypothesized to offer cooling through evaporation, transpiration, microcirculation, and shadowcasting. A notable attribute of this innovation is its design, wherein the tree’s substrate package is positioned above ground within the ambient atmosphere as displayed in Figure 5.1b. This allows the substrate to function as a sponge from which water can evaporate. This, combined with the tree’s transpiration, is hypothesized to enhance the cooling efficacy compared to a traditionally planted tree, according to a representative from Boomveer (interview, July 21, 2023).

Furthermore, the above-ground placement of the substrate package fosters an improved oxygen supply to the tree. This enhanced oxygen availability is hypothesized to promote the overall health and vitality of the tree, according to the innovation representative (interview, July 21, 2023). Moreover, the confined substrate space limits root growth and optimizes energy for growth and increases leaf density rather than root expansion, hypothetically increasing the transpiration capacity and, with that, the cooling capacity of the tree.

Additionally, the construction method used to position the tree enhances the flexibility of its branches, making them less vulnerable to external factors like wind. This reduced susceptibility to damage results in healthier tree longevity, as it minimizes leave loss from branch breakage. This, in turn, allows the tree to transpire more effectively.

Lastly, the "Boomveer" casts a checkerboard-like shadow pattern upon the underlying surface. This variation of light and shade is hypothesized to stimulate microcirculation, a concept expounded upon in the preceding section. Moreover, this tree’s shade will contribute to cooling as the shaded areas are not illuminated [Kleerekoper et al., 2012]. This effect is also hypothesized in the total cooling mechanisms but is not explicitly referred to by E.Stache as the cooling hypothesis in the Heat Square design (Interview, 3 April 2023).

Hypotheses Overview

Recapitulating on the above-described contribution of the individual design elements to the overarching hypotheses, Table 5.1 displays an overview of each of the mentioned innovations, their respective location identification corresponding to Figure 3.2, and the mitigation pathway they are hypothesized to contribute. Noteworthy is the absence of other factors commonly linked to the UHI effect, such as the albedo effect, emissivity of materials and direct cooling via shading. This absence is further discussed in Section 6.1.1 of Chapter 6.

Table 5.1: Overview of the hypothesized mitigation contribution of each included technology. The location ID in the second column refers to Figure 3.2 for clarification purposes. Results obtained from an in-person interview with E.Stache (April 3, 2023)

Innovation	**Location ID**	**Hypotheses**	
		Evapotranspiration	***Micro-circulation***
BlueBloqs Loop	1	X	
ZOAK Pavement	2	X	
Halfverharding	3	X	
Permavoid Capillair Irrigation Systems	2, 3, 4D	X	
Boomveer	7	X	X

5.2. Results - Urban Design Framework

The second phase of the framework focussed on the urban design framework, leading to the following results. Repository item analysis based on the number of phases identified within the described urban design process showed that the majority defines a set of four consecutive phases (n = 10). Fewer articles (n = 5) claim only three process steps are required to perform this process entirely, but none of the articles mention fewer. Of these articles, it is observed that the reduction of the number of phases results from combining phases, such as done in the description of Department of Infrastructure & Regional Development Australia (Producer) [2013], which combines context conceptualization and solution generation in one process step.

On the other hand, the highest number of phases identified for the performance of the urban design process is seven (n = 1), whilst one article mentions the need for five consecutive steps. Assessing the individual phases based on the objective of the phase led to the following results, which are presented according to the mentioned phases. In contrast to this linear presentation, it should be mentioned that the urban design is typically performed iteratively as depicted in Figure 5.2 [Washburn, 2015; de Groot-Reichwein et al., 2018; Kibria and Van Oosterom, 2008; Masseck et al., 2017; Cooper and Boyko, 2010]. This refers to the act or process of repeating a sequence of steps or actions to achieve a desired result or to approach a solution. It involves repeating specific instructions or operations, often intending to refine, improve, or advance a particular outcome or solution.

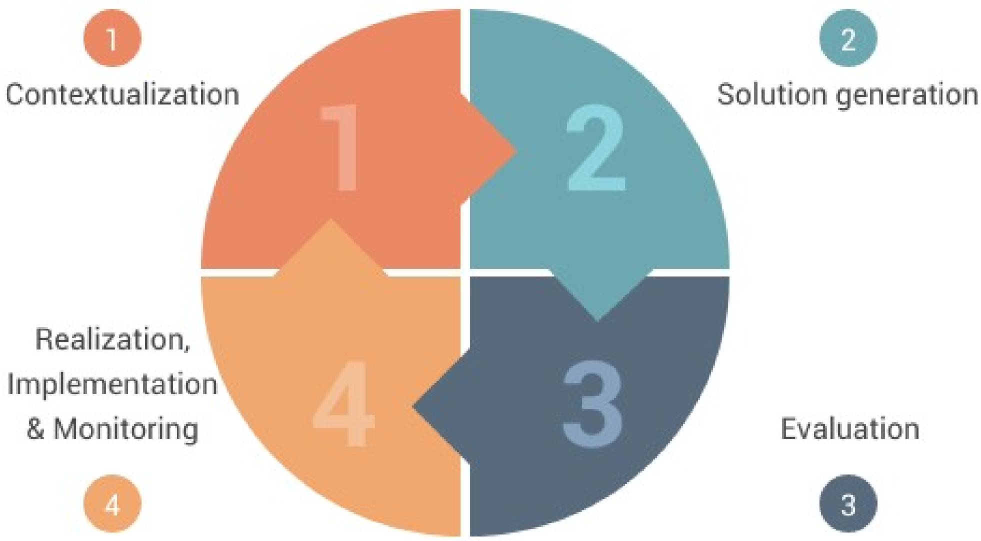


Figure 5.2: Visual Presentation of the Urban Design Framework Cycle. This figure depicts the Urban Design Framework cycle, which encompasses four distinct steps according to the results presented in Section 5.2.

Phase 1 - Contextualization

The initial phase of the urban design process focuses on contextualising the study of interest. This involves placing or interpreting information, events, or concepts within their relevant and meaningful context [Washburn, 2015; Qi et al., 2022]. It consists in understanding and analyzing the surrounding circumstances, conditions, and factors that shape and influence the subject of study [Kibria and Van Oosterom, 2008; Qi et al., 2021]. By considering the broader context, including historical, social, cultural, or theoretical frameworks, contextualization aims to provide a deeper understanding and interpretation of the subject matter. It helps to elucidate connections, significance, and implications that may not be apparent solely from isolated or decontextualized information. However, based on the consulted literature, this definition is unambiguously interpreted, resulting in a variation of acquired information. Washburn [2015]; Qi et al. [2022]; Dias et al. [2014]; Qi et al. [2021] and Boland et al. [2021] describe the need for information relating to urban characteristics such as morphology, climatology and demographics whilst others argue for the identification of influential process factors and stakeholders [Cooper and Boyko, 2010; de Groot-Reichwein et al., 2018; Lucertini et al., 2022]. Also, the need for knowledge of the legislative frameworks is advocated to be of high importance [Kibria and Van Oosterom, 2008].

Another goal often referred to within the initial phase is identifying and describing the problem (n = 7). It is claimed that a comprehensive understanding of the problem is essential for the urban design process [Dias et al., 2014; Washburn, 2015; Puig et al., 2021; Qi et al., 2022, 2021]. In contrast, research performed by Haselip et al. [2019]; Dias et al. [2014]; Cooper and Boyko [2010] argues the urban design procedure initiates with the formulation of ambitions and objective setting of the project (n = 4). Also, the generation of potential solution pathways is described within the incorporated literature [Qi et al., 2021; Puig et al., 2021].

Phase 2 - Solution Alternatives Generation

Results show that the general function of the second phase concentrates on the development, design, and/or generation of potential solution pathways that fit both the case-specific context as well as the problem identification as a result of the initial phase [Haselip et al., 2019; Dias et al., 2014; Cooper and Boyko, 2010; Boland et al., 2021; Washburn, 2015]. In total, nine (9) out of (17) articles focus on this solution generation within the second phase, with eight (8) of them identifying this as the only objective of the second phase. The remaining articles focus either on the key variables constraining implementation (n = 4) [Qi et al., 2022; de Groot-Reichwein et al., 2018; Puig et al., 2021; Qi et al., 2021]; describing the envisioned purpose of the design (n = 2) [Kibria and Van Oosterom, 2008; Haselip et al., 2019]; or public and political involvement and their role to the design process (n = 2) [Lucertini et al., 2022; Department of Infrastructure & Regional Development Australia (Producer), 2013].

Phase 3 - Evaluation

Results show that in the third phase, the most predominant (n = 11) described purpose is the evaluation of the proposed solution pathways based on a variety of ranking methods such as sensitivity analysis and multi-criteria analysis [Cooper and Boyko, 2010; Aiman, 2021; Qi et al., 2022, 2020; Lucertini et al., 2022; Boland et al., 2021]. Other purposes defined within this phase are the selection procedure of a specific solution trajectory (n = 7), which can be either in combination with the mentioned evaluation purpose Cooper and Boyko [2010], or individually on its own [Kibria and Van Oosterom, 2008; Haselip et al., 2019; Puig et al., 2021]. Furthermore, stakeholder involvement is significantly more described (n = 4) within this phase Cooper and Boyko [2010]; Haselip et al. [2019].

Phase 4 - Realization, Implementation, Monitoring

The fourth stage, described in twelve (12) out of seventeen (17) articles, predominantly focuses on realising the design plan. In this stage, the information acquired within the previous phases is aimed to be consolidated within a realization approach to the design. Articles the exact purpose of this phase are [Kibria and Van Oosterom, 2008; Haselip et al., 2019; Boland et al., 2021; Qi et al., 2020; Dias et al., 2014]. The remaining (n = 5) articles are either directed towards the evaluation of the design options or focus on the implementation, monitoring and maintenance of the design as described within Cooper and Boyko [2010]; Lucertini et al. [2022] and Department of Infrastructure & Regional Development Australia (Producer) [2013].

Additional Phases

As described above, only two (2) out of seventeen (17) repository items refer to additional phases. [Qi et al., 2020] advocates for the existence and importance of an additional phase where the chosen design is optimized using algorithms and models. On the other hand, Kibria and Van Oosterom [2008] describes three additional phases. These phases aim to consecutively present the detailed design, the functional quality plan, and the definitive design.

5.2.1. Multidisciplinary Collaboration

According to numerous (n = 12) repository items, a strong consensus emerges on the crucial role of multidisciplinary collaboration and stakeholder engagement in urban design. These sources highlight that the complexity of urban environments necessitates a convergence of cross-sectoral and multidisciplinary expertise, along with active community participation, to effectively address the challenges [Lucertini et al., 2022; Washburn, 2015; Dias et al., 2014].

Stakeholders, comprising those who can influence or be influenced by urban design, play a pivotal role [Lucertini et al., 2022; Haselip et al., 2019]. They and the broader community are encouraged to contribute insights and feedback during key phases, enhancing the overall design outcome [Dias et al., 2014]. However, due to the distinct characteristics of disciplines and stakeholders, they represent unique interest groups, possess varying expertise, and assume different roles throughout the design process [Haselip et al., 2019].

Expert integration sessions attended during the research conducted by PosadMaxwan [2023] demonstrate a pattern of iterative collaborative design steps at each stage of the design process. Different experts are strategically engaged at specific phases due to their relevance to those particular points. As each stage is completed, its outcomes cascade into subsequent stages, forming an iterative and evolving collaborative process. The early identification of relevant disciplines and stakeholders thus emerges as a pivotal factor for the successful progression of the design process [Haselip et al., 2019].

5.3. Results - Typology for UHI Effect Mitigation Technologies

The core aim of the presented result in this section is gathering a comprehensive multidisciplinary typology to describe UHI effect mitigation technologies and the implementation thereof. The results are presented following the methodology employed.

5.3.1. Typology - literature

The systematic literature review yielded a dataset consisting of 144 unique entries. Among these, most (n = 79) were mentioned only once across the nine repository items, while fewer (n = 59) appeared in two items. Results mentioned in three of the repository items included "land surface temperature," "vulnerability," "environmental impact," "implementation costs," and "energy costs". Notably, "public acceptance" emerged as the most frequently cited result, referenced in five of the nine literature sources. It's worth highlighting that no other typology result received more citations than "public acceptance" in the entire dataset. A tabular overview of this raw dataset can be found in Table B1 in Appendix B of this report.

During data processing (Section 4.3.3), a total of 60 data entries were excluded from further processing due to them being identical to data entries within the same dataset or to that of the dataset obtained via the concurrent multidisciplinary workshop approach (Section 4.3.3 step [3]). Out of the 84 included data entries, 33 exhibited no overlap in the assigned definition with the entries of the concurrent dataset (Section 4.3.3 step [4, 5]). However, the majority (n = 31) showed overlap in these definitions within its own dataset. Ultimately, this resulted in 15 distinct typologies clusters solely originating from the literature-based approach within the merged dataset (Chapter 3).

The remaining data (n = 51), those entries showing synonymy in their assigned definitions with the workshop-based dataset, underwent further processing. As a result, they were amalgamated into new typology clusters in conjunction with the workshop dataset. The analysis of these results (as outlined in Section 4.3.3 steps [6] and [7], respectively) identified the most referenced topic clusters by this dataset. As presented in Table 5.2, the results are predominantly categorized under the topics "Governmental", "Functional", and "Design" clusters as depicted in the first column of Table 5.2.

Table 5.2: Overview of the unique data entries contributing to the topic clusters per approach. N represents the number of unique data entries, whereas unique is defined as not identical to prior gathered data entries as elaborated on in Section 4.3.3.

Topic cluster	**N literature-based approach**	**N workshop-based approach**
Economical	10	19
Market	7	14
Technological Requirements	4	25
Functional	17	21
Design	14	53
Synergy	1	13
Social	5	18
Governmental	17	13
Impact	8	35
Implementation & Application	1	10

5.3.2. Typology - Multidisciplinary Workshops

This study's four workshops, including the testing phase, yielded a raw dataset of 259 distinct typology results. The cumulative contribution of each workshop to this dataset is visually presented in "raw data" format within **??**. Following data processing, 221 of these data entries were identified as unique, which is also depicted in Figure 5.3 per conducted session. Analysis of the latter showcased a saturation setpoint of 27% for the last conducted workshop. The remaining dataset with unique entries (n = 221) was thereafter processed based on their assigned definitions, where entries with synonymical definitions were removed. This yielded a dataset of 131 data entries from the workshop-based approach solely (hence excluding the merged data from the literature approach). Thereafter, clustering overlapping synonyms into new typologies resulted in a total dataset of 82 entries, further classified according to 10 cluster topics. Of that dataset comprising of unique typologies (n = 131), the second column of Table 5.2 gives an overview of how these clusters are accounted for in terms of data entries per topic cluster. Appendix B of this report contains the full processed dataset from this approach.

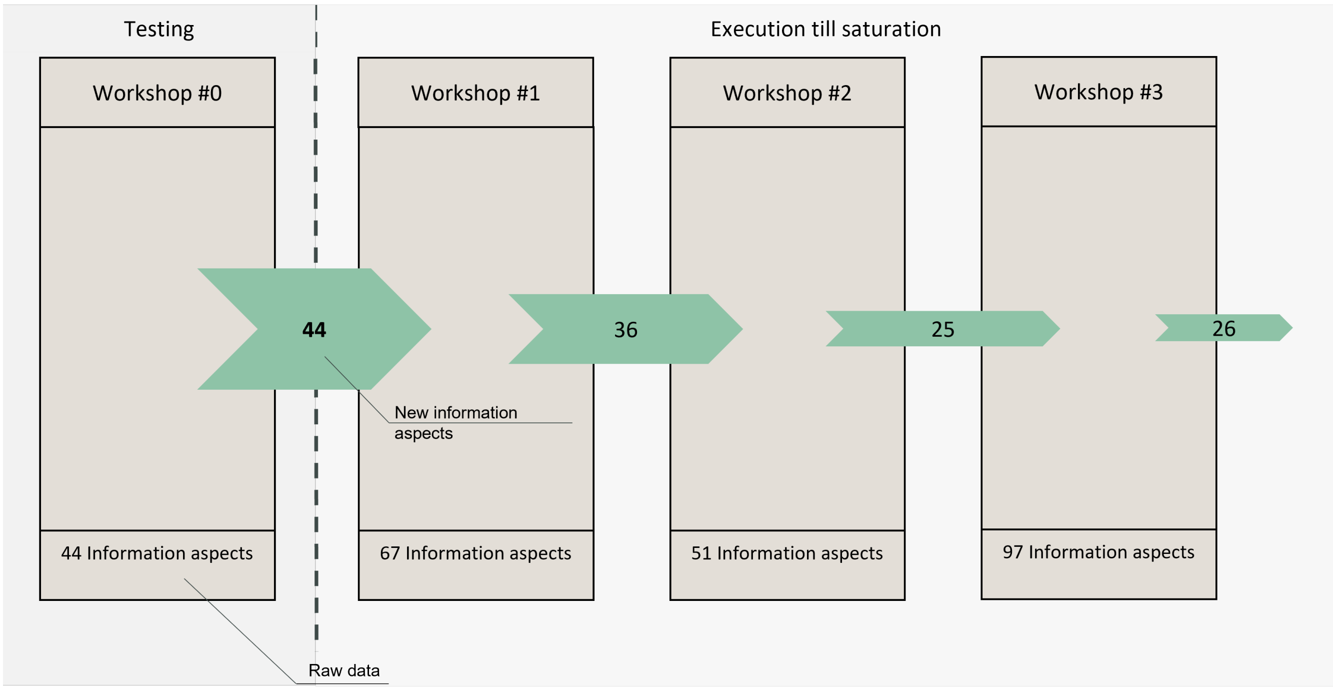


Figure 5.3: Workshop iteration process. From left to right, the conducted workshops are presented. The "testing" phase of the workshop is placed separately from the succeeding workshops as it contains a distinct objective. Each workshop session presents the raw data produced (bottom of each figure) whilst the green coloured arrows present the unique data entries, according to the data processing procedure, of each workshop session. These unique data entries are referred to as "New information aspects"

5.3.3. Combined Typology Results

A cumulative total of 363 raw data entries were acquired, integrated, and subjected to processing within the scope of this research. A notable proportion, exceeding 20% (n = 86), was identified as duplicates from prior collections and thus excluded. Among the residual dataset (n = 277), nearly 45% (n = 121) were eliminated due to the synonymy of the assigned definitions. A supplementary set of 58 data entries was similarly excluded as they exhibited synonymical overlap with the assigned definitions of other entries, thus amalgamated into clustered typologies. The amalgamation of the concurrent datasets culminated in a comprehensive dataset of 98 distinct typologies and their corresponding definitions categorized in 10 topic clusters.

The combined dataset is subdivided into ten subsets according to the defined topic clusters. Due to the extensiveness of the entire dataset, one of these subsets is partially shown below in Figure 5.4. The initial row of each subset presents the topic of that particular subset. The second row describes the columns in which the subset is constructed. The first and second column of the table, "Unique data entry" and "Definition", depicts all data entries and their assigned definition, respectively, that are defined by the data processing procedure as unique. This holds that the typology itself, as well as its assigned definition, does not correspond to a previous data entry. For example, in the subset below, "Costs" and "Costs/m2" are similar typologies and overlap in their assigned definitions. However, they are not identical based on the typology and definition and are therefore presented as unique. The third column of the table presents the typology clusters based on the overlap in definitions described in the second column. Again, for typologies "Costs" and "Costs/m2", the example is drawn where these typologies, together with other typologies, are clustered into an overarching typology encompassing all incorporated data entries. The final column of this table presents the assigned definition of the typology cluster, which is developed based on all the individual definitions of the incorporated data entries.

Furthermore, it should be noted that shading is provided (grey) for data entries that specifically originate from the literature-based approach only. This means that data entries shaded in grey, for example, "Costs of capital", only occurred in the dataset obtained from the literature-based approach and were assigned to be unique during the data merging process. When shading is provided over the entire row length, including the third and fourth columns, the typic cluster is solely based on data entries from the literature.

A comprehensive version of the dataset result, presented in its entirety, is available in Appendix B of this Report.

Economical			
Unique data entry	**Definition**	**Typology cluster**	**Cluster definition**
Costs	This refers to the total expenses of a technology or service over its entire lifecycle. Costs encompassed in this are costs incurred during the design, development, production, distribution, maintenance, etc.	Total Cost of Ownership (TCO)	Total Cost of Ownership refers to the comprehensive financial evaluation of a technology or service throughout its entire lifecycle. It encompasses all costs incurred during the design, development, production, distribution, maintenance, and operation of the technology. This includes initial capital costs, hidden costs, maintenance costs, and operational costs over the lifespan of the product or service. TCO allows for a holistic assessment of the financial expenditure associated with the technology, taking into account both visible and hidden costs, enabling better evaluation of economic feasibility and efficiency.
Embedded costs	Refers to the total costs associated with the technology, including initial capital costs, maintenance costs, and operational costs over its lifespan. These costs are typically hidden and difficult to measure but they can have a significant impact on the overall costs of the product or service.		
Investment costs	Investment costs refer to the total expenses associated with making a financial investment in a project, asset, or business opportunity.		
Cost of capital	Capital costs refer to the initial expenses incurred in acquiring, constructing, or establishing a new project, facility, or investment.		
Costs / m2	Cost per square meter is the financial expenditure associated with UHI mitigation technologies measured on a per-unit area basis. It includes material, labor, installation, operation, maintenance, and energy costs, enabling evaluation of economic feasibility and efficiency.		
Ownership costs	The costs associated with owning and maintaining a technology over its lifespan.		
Costs of implementation	Refers to the costs associated with installing the technology, including labor, equipment, and site preparation.	Implementation and installation costs	Refers to the total expenses associated with implementing and installing a particular technology solution, including costs such as hardware and software purchase, licensing fees, installation fees, labor, equipment, site preparation, training expenses, and other related costs.
Installation costs	The expenses associated with the setup and configuration of a technology or system, including hardware, software, and labor costs.		
Surcharge costs for installation	Additional fees or charges that may be added to the installation costs of a technology or system, such as taxes or shipping fees.		

Figure 5.4: Partial Compilation of Merged Typology Dataset. Gray-shaded entries represent distinct typologies sourced from literature. This dataset should not be solely referenced, as it is part of the comprehensive typology dataset presented in Appendix B.

5.4. Results - Interface Conceptualization

Three key outcomes emerge in the last phase of the developed framework, focusing exclusively on the Boomveer innovation. First, the typology results from the third framework phase are converted to a questionnaire format tailored to the Boomveer innovation. This questionnaire format is subsequently utilized in an interview conducted with a company representative of the invention, resulting in the collection of pertinent data in response to the typologies. Lastly, the previous result is integrated into a digital interface conceptualization, forming this phase's final outcome. The subsequent sections delve into these outcomes. While the first two outcomes are presented together due to their interconnection, the results stemming from the interface development are presented individually. Access to the whole interface conceptualization product is accessible via the following link [redacted]

Due to sensitivity of provided information,
this link only available on request.

5.4.1. Data Collection

To gather data for the interface conceptualization, the comprehensive typology results from the third phase, detailed in Section 5.3, are processed into a structured questionnaire format. This format is subdivided into ten subsets according to the identified topic clusters. A sample from one of these subsets is illustrated below in Figure 5.5

Each subset starts with a row indicating its corresponding topic cluster, followed by a row outlining the table columns. The first and second columns display unique data entries of the merged dataset and their respective typology clusters, maintaining consistency with the combined typology table (Section 5.3.3). These columns serve as reference points for interviewers and questionnaire participants to grasp the elements underpinning each question. The third column presents the question with a suggested response format to guide interviewers and participants in providing information. Subsequently, the fourth and fifth columns of the table record the results obtained from interviews or questionnaires. These results are categorized into high-level responses, typically summarized in single phrases or numerical values, and detailed answers allowing for more elaborate descriptions, as elaborated in Section 4.4 of Chapter 4. The last column of the table facilitates the inclusion of external references, such as publications or websites, to substantiate the provided information.

It is important to note that, for the data collection, this questionnaire is tailored to the Boomveer innovation as technology that is considered for full framework development in this research. This customization is reflected in the complete presentation of the results. Entries marked with the label "not for Boomveer," such as the typology cluster and question: "Color-surface Temperature Relationship" - "What is the relationship between the colour of the surface of the innovation and its impact on the surrounding temperature?" include typologies that are not relevant to this particular innovation.

Furthermore, instances where the company representative was unable to provide a high-level response to a question are indicated by the phrase "no high-level answer available," as demonstrated in the typology cluster and question: "Required parties for technology promotion" - "What parties are required for the realization, promotion, or implementation of the innovation?"

A comprehensive view of the questionnaire format in general and the format tailored to the Boomveer innovation are available in Appendix C of this report. The results of this tailored questionnaire are only available on request because it contains sensitive information.

Economical					
Unique data entry	**Typology cluster**	**Question**	**High level answer**	**Detailed answer**	**Source**
Costs Embedded costs Investment costs Cost of capital Costs / m2 Ownership costs	Total Cost of Ownership (TCO)	What is the Total Cost of Ownership (TCO) over products entire life cycle? [euro / unit / year]	1000 euro / unit / year	500 product [euro / unit / year] 125 overhead [euro / unit / year] 375 integral management [euro / unit / year] Holds for minimal product time between 8 to 16 years	
Costs of implementation Installation costs Surcharge costs for installation	Implementation and installation costs	What are the total costs of installation of a product? [euro / unit]	150 euro / unit (for ground level implementation)	Installation is very easy and cheap compared to a planted tree. On Ground level the Boomveer only needs to be lifted of the transportation vehicle and placed into position. Relatively easy process and does not required longer than 15 minutes. Implementation on higher levels (roofs etc.) requires more difficult procedures. Depending on the location characteristics the procedure and duration of implementation varies. Moreover, the Product itself, referring to the construction frame of the Boomveer, can and sometimes needs to be adjusted to enable installations. These could too contribute to additional costs.	
Management costs Running costs Operating costs Water costs Energy costs Maintenance costs per m2	Maintenance and Management Costs	What are the total costs of integral management of the tree? [euro / unit / year] Specify: - Water costs - Energy costs - Pruning costs - Labor costs - Other	Approximately 3000 euro over entire product life time 375 [euro / unit / year] Indicative!	Integral management costs of a single unit is depended on the location of implementation and the associated and specific requirements of the tree. Therefore standardization of the integral management costs is not possible. The Urban Jungle Project provides therefore different levels of integral management (low to high) which varies in intensity, frequency and cost.	

Figure 5.5: Partial presentation of the "Economical" topic subset of the interface data collection results. This dataset should not be solely referenced, as it is part of the comprehensive dataset presented in Appendix C

5.4.2. Interface Description

A digital platform is obtained by the interface conceptualization phase of the framework aiming for integrating UHI effect mitigation knowledge multidisciplinary. The platform is constructed from different "pages" developed to present knowledge and guide users towards this knowledge.

The first page of the platform introduces the user to the Heat Square at TGV. Here, users are guided to proceed to the second interface page titled "Platform Overview" (Figure 5.6).

This "Platform Overview" page is the entry point for users to select their specific areas of interest for exploration within the platform. Although this interface concept serves multiple intended end-users, this section outlines the general functionality designed to serve them all.

Firstly, a platform guidance environment (Figure 5.7) has been established to give all users essential information to comprehend the tool's functionalities and provide navigation assistance. This guidance ensures users interact with the platform effectively and transparently communicate any limitations.

Secondly, to provide users with background knowledge about the central issue this platform addresses — the UHI effect — relevant information is presented in concise statements. It's important to note that the platform doesn't delve into the description of the problem extensively. Instead, it offers references to the core statements and provides detailed elaborations on the topic through active links, directing users to relevant sources.

The main content of the interface is accessible via the "The Solution" page (Figure 5.8). This section introduces users to the outcomes derived from the second phase of our framework, focusing on the mitigation hypotheses associated with the Heat Square design. Here, users can delve into the primary hypothesized cooling pathways. Additionally, users can continue their exploration of mitigation solutions by navigating to the "Innovation Overview" (Figure 5.9). Here, the technologies within the scope of this research are presented alongside their specific hypothesis results. Notably, as the whole framework is exclusively applied to the Boomveer innovation, this emblem is clickable, redirecting users to the innovation-specific environment, which will be further detailed in the end-user experiences section outlined in Section 5.4.4.

Finally, the last general functionality of this platform is depicted in the top right corner of every page as two "conversation clouds". As explained in the platform guidance, clicking on this emblem redirects users to the "Feedback & Questions" page (Figure 5.10). Here, users can provide feedback or pose questions related to various aspects (including General inquiries and innovation specifics) and various topics (e.g., functionality, economics, market, etc.).

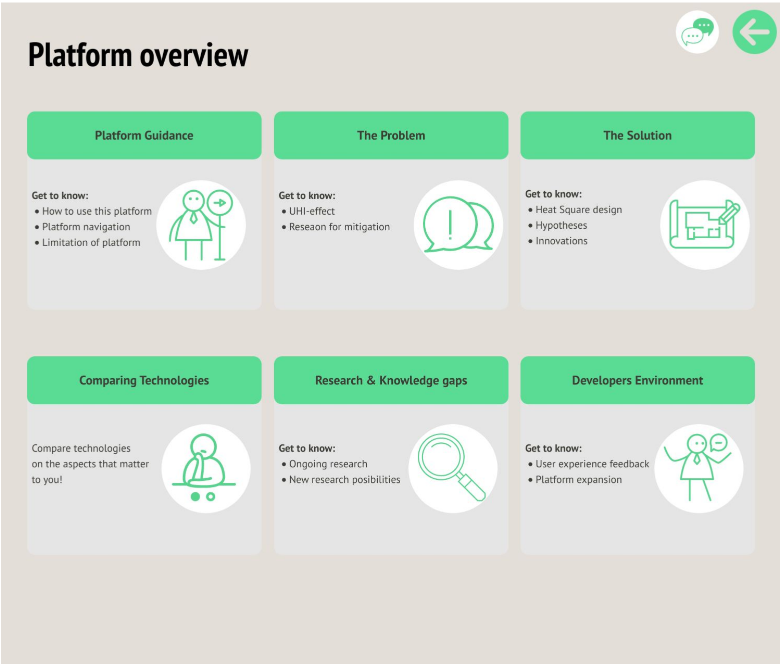


Figure 5.6: Image of the "Platform Overview" of the developed interface concept.

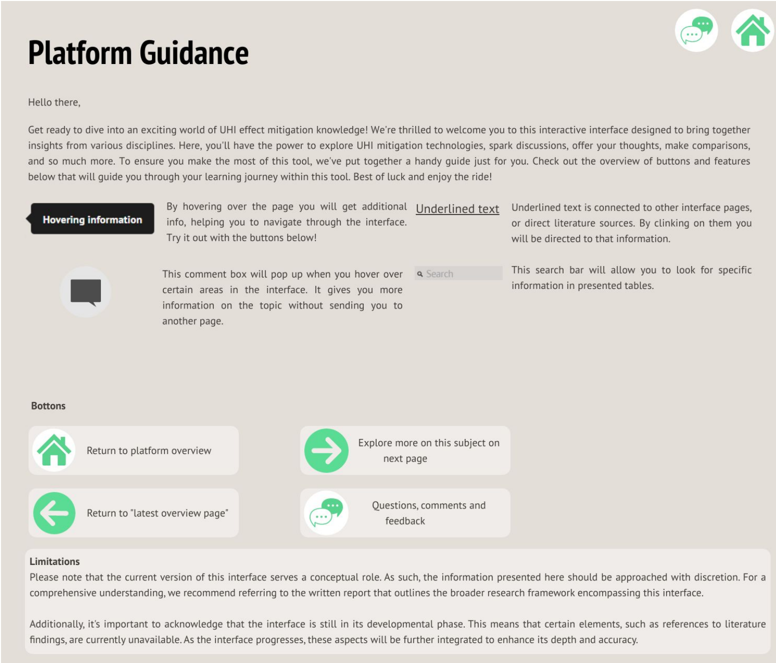


Figure 5.7: Image of the "Platform Guidance" of the developed interface concept.

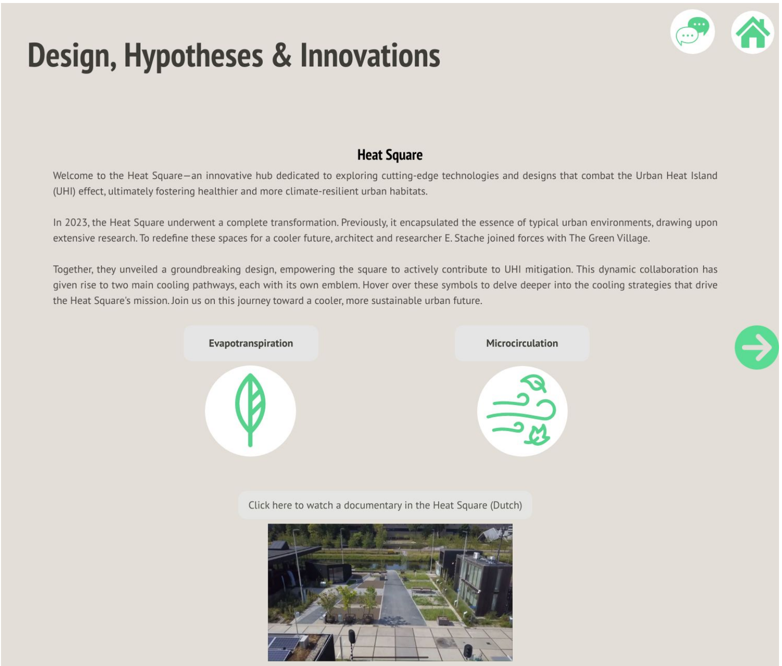


Figure 5.8: Image of the "The Solution" of the developed interface concept.

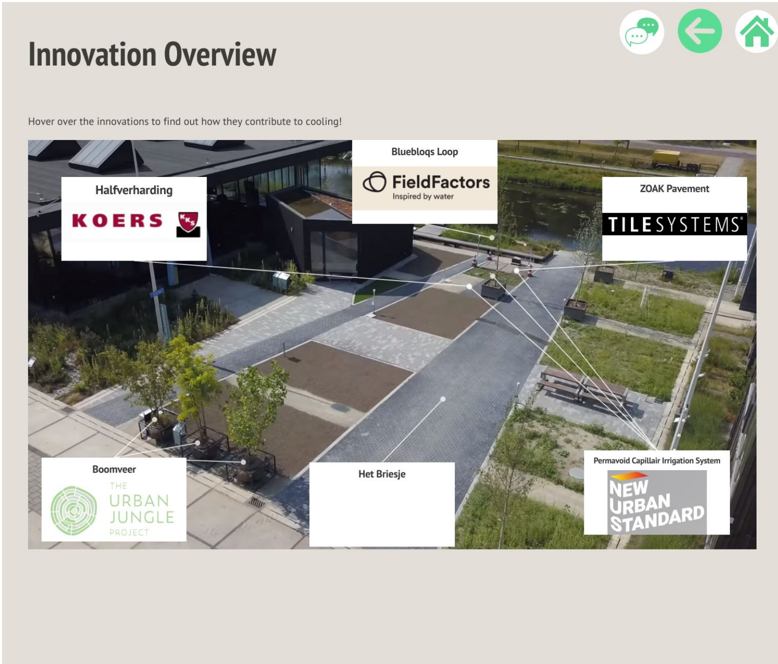


Figure 5.9: Image of the "Innovation Overview" of the developed interface concept.

5.4.3. Content Presentation

The interface concept organizes content into distinct environments detailed in Figure 5.6. It categorizes content into "general" and "innovation-specific" sections, with the latter exclusively available for Boomveer innovation. The innovation-specific content offers varying levels of detail.

Users start at the general innovation page (Figure 5.11), which presents hypotheses from the second phase of our framework supplemented by data from the innovation's dedicated webpage. This page introduces the specific technology.

To explore innovation-specific content further, users click on topic clusters at the bottom right corner, corresponding to typology results (Section 5.3). Selecting a cluster, like "Economical" (Figure 5.12), provides high-level responses from framework phase 3 interviews (available on request). It offers straightforward information on typology clusters, e.g., "Total Costs of Ownership." Detailed answers can be accessed by clicking typology clusters on this page, directing users to specific typology descriptions (Figure 5.13).

This approach is consistent across all typology clusters and interview results, using visual aids like graphs, maps, images, and icons for clarity and interactivity.

Figure 5.10: Image of the "Feedback & Questions" of the developed interface concept.

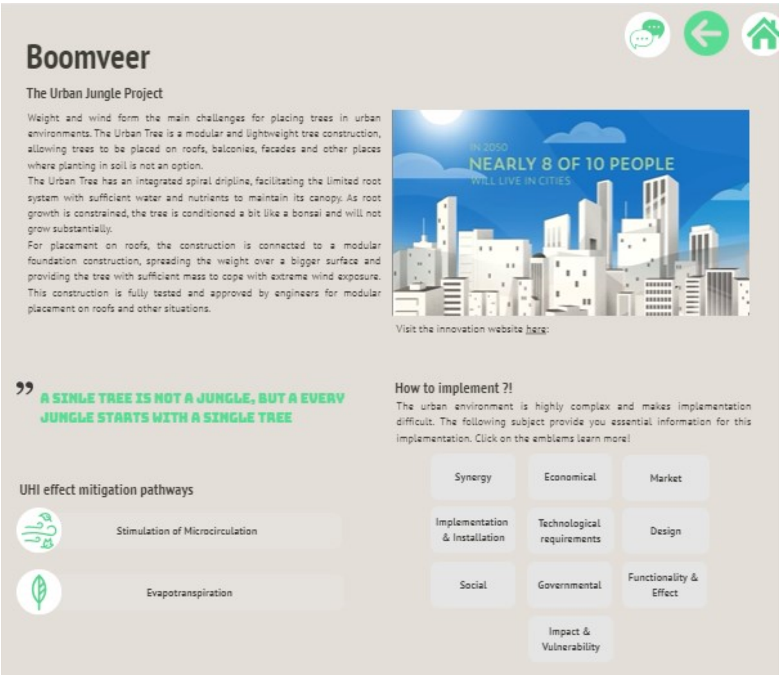


Figure 5.11: Image of the "Boomveer Innovation Overview" of the developed interface concept.

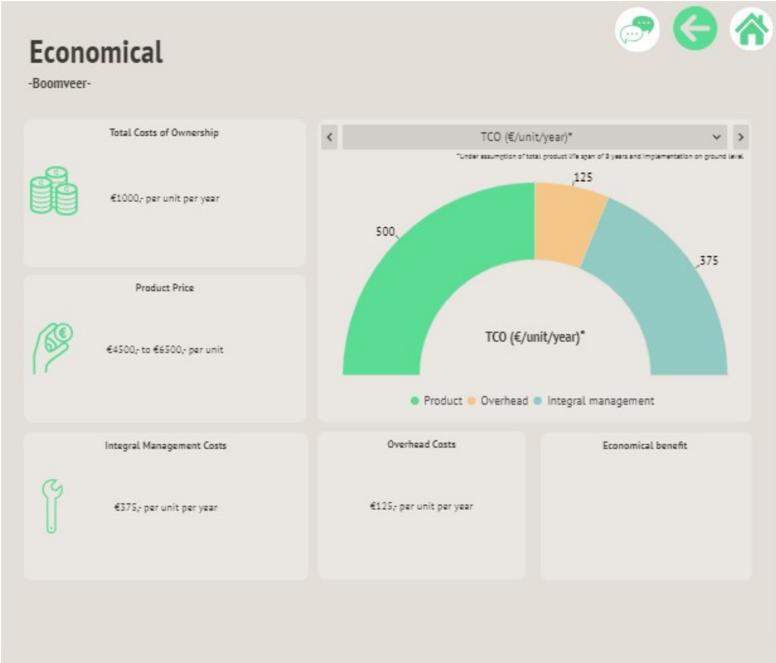


Figure 5.12: Image of the "Economical" content of the Boomveer innovation in the developed interface concept.

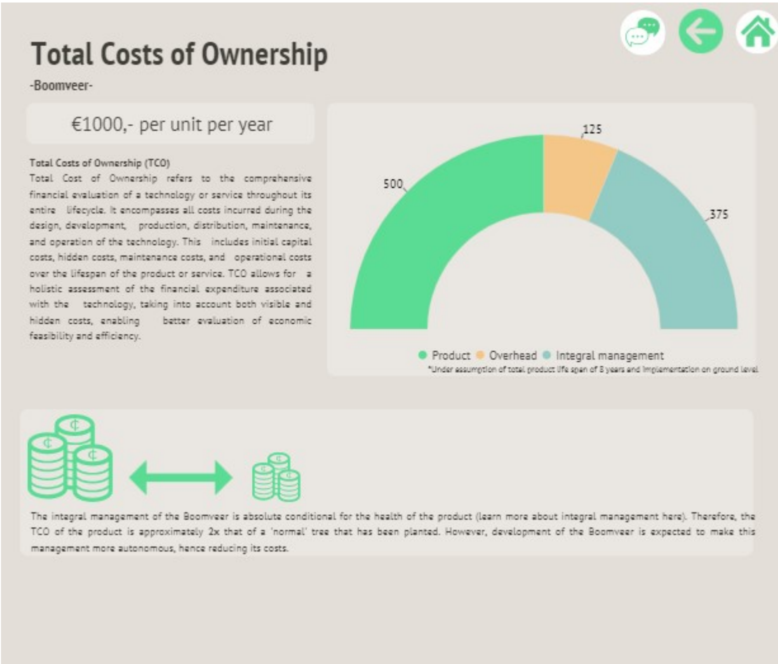


Figure 5.13: Image of the "TCO" content of the Boomveer innovation in the developed interface concept.

5.4.4. User Experience

As presented in Section 4.4.1, four user profiles are identified as prospective end-users. The proposed requirements for each end-user are processed into the interface conceptualization, resulting in four distinct envisioned user experiences of the developed concept.

Researcher

The specific interface page, "Research & Knowledge Gaps" (Figure 5.14), was developed to meet the requirements of the "Researchers" user group. This page overviews ongoing research activities at the Heat Square and highlights unanswered research questions related to the presented interface content. Contact information for researchers and research initiators is included to facilitate collaboration and communication.

Furthermore, the interface includes direct links to detailed sources, such as literature reports, books, or research outcomes, allowing researchers to access the original sources for verification.

Additionally, researchers, along with other users, can contribute new research questions through the general feedback functionality. This feature is particularly relevant to researchers, as it aligns with their unique role in generating and advancing knowledge within the interface.

Innovation Developers

Innovation developers are defined as the end-users of which their technology is presented within the envisioned interface. In the current version, this is the developer of the Boomveer. Through their dedicated page, accessible via the platform overview, they are forwarded to a log-in environment, enabling them access to a specific developers page (Figure 5.15).

In this environment, the user is presented with a comprehensive overview of end-user feedback and raised questions specified to their technology. This overview is structured based on the topic, one of the features of the general "Feedback & Question" page. Moreover, a search bar is provided for quick navigation in this feedback database.

Furthermore, this page is envisioned with a bar graph presenting the most consulted information. This is based on the number of end-users consulting the specific topic pages belonging to their innovation, resulting in a qualitative indication of which information is most looked for. Additionally, end-users are able to compare the content of various technologies simultaneously. An overview is proposed presenting technologies that are most frequently compared to theirs.

Lastly, developers have the capability to modify the content applicable to their innovation. This feature aligns with the interface's commitment to continuous improvement and expansion. Developers can make adjustments, introduce new information, and include references, all contributing to interface enhancement. Importantly, as outlined in the proposed list of requirements, any content changes trigger notifications to the platform manager to ensure the accuracy of presented information

Platform Manager

The envisioned platform manager, represented by TGV due to their ownership of the Heat Square premises, does not have a dedicated environment within the interface but plays a crucial role in its functionality. Notably, the interface content is designed to be adjustable by the platform manager at any time. This adaptability extends to all displayed content, including technology-specific information.

This feature is pivotal because it allows research findings from the Heat Square to be promptly and directly integrated without any influence from technology innovators to minimize potential bias in information presentation.

Moreover, the platform manager is the recipient of all comments and feedback provided by users. While innovation developers also receive comments and questions specific to their technologies, the platform manager collects all feedback, encompassing a broader perspective. This is because TGV as the platform manager holds a more general stance regarding innovation development and can initiate new research queries based on their own perspectives and findings, supported via the "Research & Knowledge Gaps" page.

Main end-users

The primary end-users in this research referred to as "main end-users," encompass individuals involved with the implementation, assessment, or both, of UHI effect mitigation technologies. Their pivotal role in shaping the typology during the third framework phase has substantially influenced the interface's design. As a result, the informative content within the interface is tailored to align with their specific requirements. Moreover, the interface's content structure empowers these main end-users to explore information at varying levels of detail, tailored to their preferences.

Additionally, the interface's continuous development relies on a high level of engagement from end-users. End-user activity is hypothesized to yield a substantial volume of feedback, aiding in the identification of areas where information may be lacking. The interface's feedback feature allows end-users to communicate new information requirements, thereby contributing to the expansion of the typology results and, consequently, the overall improvement of the tool.

Furthermore, inspired during the integration session at PosadMaxwan (integration session "handbook on designing with/for vital soils in urban areas", 28 February 2023), the "Comparing Technologies" page was developed (Figure 5.16). Although still in the developmental phase within the interface concept, this page offers a comprehensive platform for comparing technologies. It provides two modes of comparison. In "Version A," end-users can select specific topics of interest during their interaction with the interface, and at the conclusion of their user experience, they can visit the comparison page to view all selected items side by side. In "Version B," a more streamlined approach is taken, allowing end-users to swiftly access an overview and select a specific topic (e.g., costs) to see results across all implemented technologies.

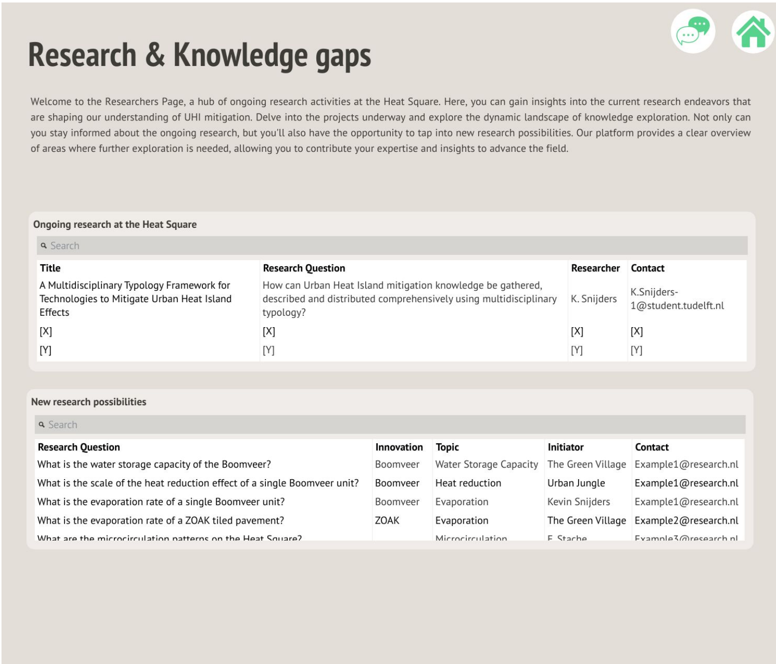


Figure 5.14: Image of the "Research & Knowledge gaps" of the developed interface concept.

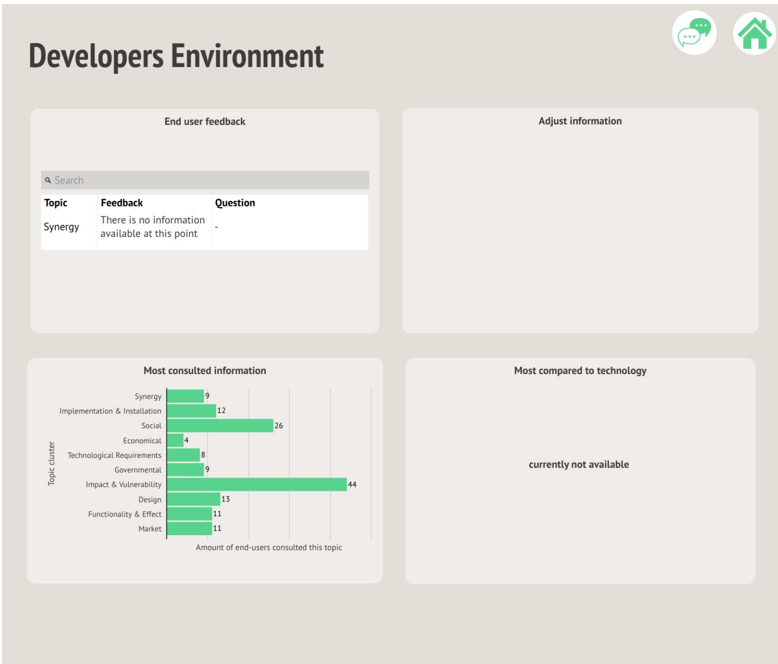


Figure 5.15: Image of the "Developers Environment" of the developed interface concept.

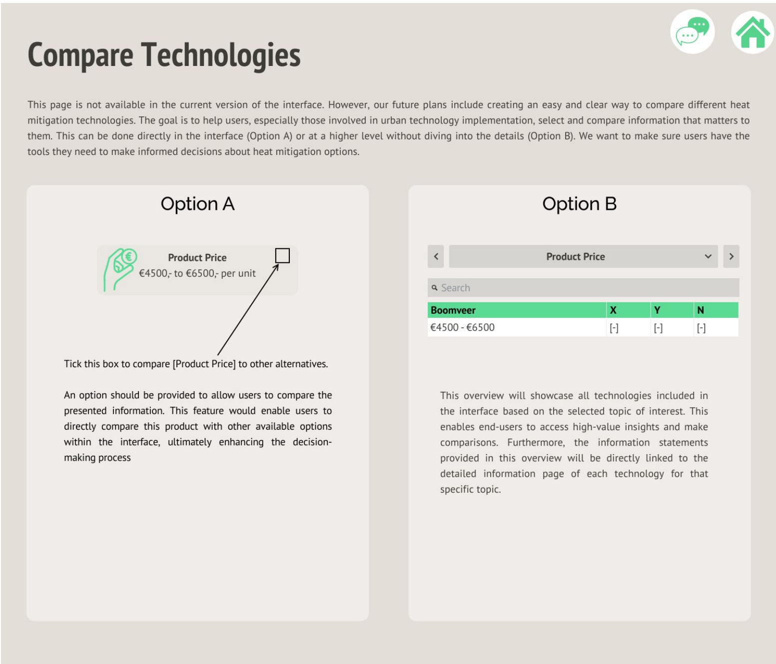


Figure 5.16: Image of the "Compare Technologies" of the developed interface concept.

6 Discussion

With the aim of multidisciplinary knowledge integration and dissemination, a systematic framework consisting of four phases has been designed and implemented to achieve this. Each phase has individual outcomes contributing to the overall narrative. The framework itself and the outcomes it produced will be discussed in this chapter.

The subsequent sections first elaborate on the implications of the outcomes of each phase. For clarification purposes, the phase's applied method, core objective, and results are summarized in Figure 6.1 up and till Figure 6.4 respectively. Thereafter, the implication of the entire framework, including its relevance to the applied case study and its potential applicability beyond that context, will be expanded on in this chapter.

This chapter will finalize by examining the limitations and challenges encountered throughout this research and offer recommendations for further research.

6.1. Implication of Framework Results

6.1.1. UHI Effect Mitigation Hypotheses

A qualitative description of the hypotheses of the new Heat Square design and the integrated technologies remained absent at the initiation of this research (February 2023). During the first framework phase, this gap was addressed through hypothesis statements provided by lead designer E.Stache on the assumed cooling mechanisms and the functionality of the integrated technologies to those mechanisms (interview, April 3, 2023). Hypotheses for the Boomveer innovation were supported by the statements provided by a company representative (interview, July 21, 2023). For the remaining technologies within this study's scope, no company representatives were consulted, yet hypotheses statements from Stache were supported by the information presented on the technology's respective web pages.

Secondly, comprehensively providing information on multiple technologies in an integrated design is currently lacking in existing literature [Santamouris and Kolokotsa, 2016; Aleksandrowicz et al., 2017]. According to their research, analysing current trends in UHI mitigation studies, synergetic potentials and effects of multiple technologies within an integrated design are hardly accounted for, albeit neglected. The hypothesis results obtained in this research contribute to closing this gap by hypothesising the need for multiple technologies to redirect incoming energy into latent heat via evaporation and transpiration processes and extract this latent heat by stimulating microcirculation. These findings support the claim of Gunawardena et al. [2017] that effective UHI effect mitigation strategies should focus more on designs integrating various technologies with synergetic interplay.

These hypotheses' results are also pivotal in the overarching objective of knowledge integration through the developed interface concept (orange arrow, Figure 4.1). Especially for innovative technologies, which specifically focused on within the scope of this research, lack acknowledged studies proving their functionality to mitigate heat. This holds for the overall Heat Square design and its integrated technologies. The lack of this evidence should not impede the development or knowledge integration. Therefore, hypothesis statements are used as an initial informative framework to integrate knowledge on newly arising technologies and principles. However, given their hypothesis status, these outcomes should be interpreted carefully as the presented information must still be validated by research. However, this validation will assumed to be performed relatively easily due to the ongoing research activities (qualitative and quantitative) at the Heat Square. Moreover, it is noteworthy that this very characteristic aligns with the envisaged progressive trajectory of the interface, as the absence of substantiation underscores remaining gaps in knowledge. This identification, in turn, is assumed to stimulate and effectively guide new research activities, thus enhancing future knowledge integration within the field of UHI mitigation.

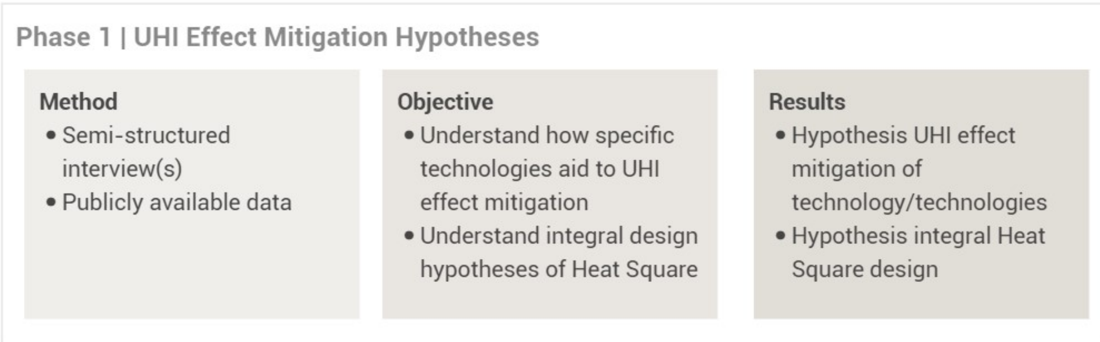


Figure 6.1: Illustration of the First Framework Phase. This figure comprehensively depicts the applied methodology, the primary objective, and the central outcomes achieved during the execution of the initial framework phase.

6.1.2. Urban Design Framework

In examining the urban design framework, key findings have underscored it as a multidisciplinary iterative cycle, generally encompassing conceptualisation, solution generation, evaluation, realisation, implementation, and monitoring. However, this framework is generally adapted to case-specific requirements and the intended objectives of the project causing variation in the significance of the phases as well as the activities performed within them.

For effective urban design, emphasis is placed on stakeholder involvement from experts and the community. Yet, the research findings reveal a notable absence of a standardised overview of the disciplines involved in these processes. Consequently, the research falls short in guiding the selection of participants throughout the sequential phases of the framework of this research. This variability in stakeholder consultation is attributed to the inherent complexity and transformative nature of urban environments, the evolving roles of stakeholders across different phases, and the specific input requirements that stakeholders bring to each phase and the overall process [Washburn, 2015; Cooper and Boyko, 2010; Haselip et al., 2019; Dias et al., 2014; Lucertini et al., 2022].

Given this absence of standardised stakeholder involvement, the key findings emphasise the necessity for early identification and the establishment of an effective stakeholder engagement [Haselip et al., 2019; Cooper and Boyko, 2010; de Groot-Reichwein et al., 2018; Lucertini et al., 2022; Washburn, 2015; Dias et al., 2014]. In one of the literature reports referenced in this study, a comprehensive document outlines how this process could be conducted. Rogat [2015] describes that in this process, all stakeholders pertinent to the project should be identified and categorised according to their respective roles to generate a comprehensive overview of all activities requiring attention and the stakeholders associated with each activity. Furthermore, the identified stakeholders should undergo assessment, gauging their influence and interest in the project using the "Hovland Stakeholder Interest/Power Matrix" [Hovland, 2005]. According to Rogat [2015], this assessment should be conducted for all stakeholders at every phase of the urban design framework to ensure proper stakeholder involvement. Classifying each stakeholder into specific groups based on this Hovland matrix facilitates a focused approach to the stakeholder involvement process. For instance, stakeholders with low interest and power should receive consistent updates throughout the process. Still, their involvement in decision-making should be limited in contrast to stakeholder groups with substantial power and high interest.

Regarding this research, the above approach was not used to identify and involve stakeholders. Additionally, ethical guidelines prevented gathering information for participant identification, making it difficult to describe their role in the design cycle. However, based on the analysis of the general descriptions, an absence of operators, contractors, citizens, and disciplines related to system operation, maintenance, and management became evident. Ultimately, this limits stakeholder involvement and multidisciplinary knowledge integration in the developed typology.

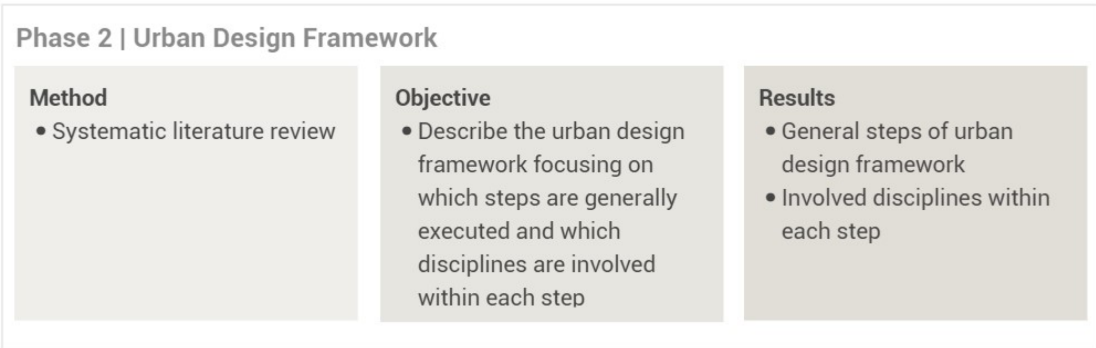


Figure 6.2: Illustration of the Second Framework Phase. This figure comprehensively depicts the applied methodology, the primary objective, and the central outcomes achieved during the execution of the initial framework phase.

6.1.3. Typology for UHI Effect Mitigation Technologies

Typology as data format

In the UHI mitigation research, utilising typologies for knowledge collection, presentation, and integration is a new approach. Conventionally, the field has relied heavily on methods like synthesis reports, practice-oriented articles, and performance assessments of implemented strategies [Lowe, 2016].

However, it's worth noting that these conventional approaches demand considerable time and resources, making it "unlikely that the performance of many Urban Heat Island Mitigation

Strategies will have been monitored" [Qi et al., 2020](p.14) and limiting the range of technologies presented. In particular, for new emerging technologies, a shortage of such reports and general knowledge integration is lacking, causing underdevelopment in implementation guidance [Hoffmann et al., 2017] which consequently hinders their development [D'Este et al., 2012]. In contrast, the use of the typology format in this study does not discriminate based on the maturity of the technology and applies to a diverse range of technologies. While typologies may contain technology-specific details applicable only to particular types (for example, pruning requirements relevant to vegetation-based technologies), most typologies are general and apply to any technology (for instance, "costs", "maintenance requirements", and "public acceptance").

These typologies result from a combined effort, drawing from existing literature reports and newly conducted multidisciplinary workshops. Notably, while the predominant focus in the field has been on performance metrics [Lowe, 2016; Hoffmann et al., 2017], other essential aspects like "environmental impact" and "public acceptance" have been overlooked, as highlighted by [Qi et al., 2020; Hartog, 2023]. The concurrent mixed-method approach adopted in developing these typologies allows for incorporating these diverse criteria, making them more robust and comprehensive [Lawrence et al., 2022].

Furthermore, since these typologies are based on literature findings and input from practical disciplines, they possess adaptability. This adaptability means new indicators introduced in current formats and emerging practical questions can be integrated into the typology framework. This flexibility is a significant advantage over current formats, often constrained by time and resource limitations.

Another notable feature of the typology is its absence of hierarchy, where each typology holds equal value. While this approach has limitations, as discussed in Section 6.3, it enhances the applicability of knowledge across diverse contexts. Given the complex nature of the urban environment, informational requirements vary from case to case and require tailor-made tools [Özerol et al., 2020]. By eschewing hierarchical structures, the typology format empowers stakeholders within individual cases to identify the knowledge that is relevant to their unique context, rather than a conventional format that displays information of high hierarchy that might only fit the requirements of a specific end-user group [Hoffmann et al., 2017].

Typology method reflection

Other advantages of the typology format focus on the reflectance of the applied approaches regarding the robustness and comprehensiveness of the gained data. First, as the concurrent datasets are merged, a saturation setpoint of 58% would be observed following the calculation method as applied in the workshops (Section 4.3.3 step [3]). This implies that 58% of all unique typology results were not obtained if only the workshop-based approach were consulted solely. Consequently, it indicates that both approaches complement each other, resulting in a more robust and comprehensive dataset. However, this assumption should be interpreted with care. Based on the excluded and merged typology results, based on the assigned definition, a much lower saturation value is observed (23%). This implies that, although the literature results are unique based on the typology itself, their uniqueness is less when assessed based on the definitions of the typologies. Although conducting a saturation point analysis on this "data assigned definition uniqueness" was not pursued due to potential biases, this observation suggests that the contribution of the literature-based results to the combined typology dataset is less than initially thought and that combining these datasets results in a gradually decreasing trend of new results as the one presented in Figure 5.3.

Secondly, it should be noted that the topic contribution of each approach varies between the conducted approaches. As the literature-based data mostly favours the topic clusters "Functional" and "Governmental", the workshop-based data does so for "Design" and "Impact" according to absolute data numbers (Table 5.2. When analysed per cumulative number of both approaches contributing to the clusters, it is observed that the "Design" topic is most represented. However, as the participants included in the workshops are more represented by design disciplines rather than others, this gravitation of the dataset towards this topic could be declared. This effect can also be observed by calculating the standard deviation of data contribution to each topic, which showed values of 5.73 and 13.29 concerning the literature-based and workshop-based data, respectively. This observation suggests that the literature-based data is more evenly distributed, while data acquired from the workshop is more favoured towards a single or set of disciplines. These observations together form a critical limitation of the workshop to the participant representation of the disciplines, which will be further elaborated on in Section 6.3.

Finally, the analysis of concurrent methods highlights a notable discrepancy in result specificity between literature-based and workshop-based approaches. While literature often provides broad categories like "Costs," the workshop results offer a more detailed breakdown, including "installation costs," "management costs," "costs of capital," and "product price." Additionally, workshop-generated typologies, such as "mosquito infestation" (referring to the potential of the technology or the environment created by the technology that promotes conditions suitable for mosquito breading) and "Shoe Cleanliness" (referring to the level of dirt or debris that may accumulate on shoes when walking on or interacting with the technology), are too specialized to be accommodated within the hierarchical structure of literature. Consequently, the workshop-based approach predominantly contributes to identifying specific knowledge requirements.

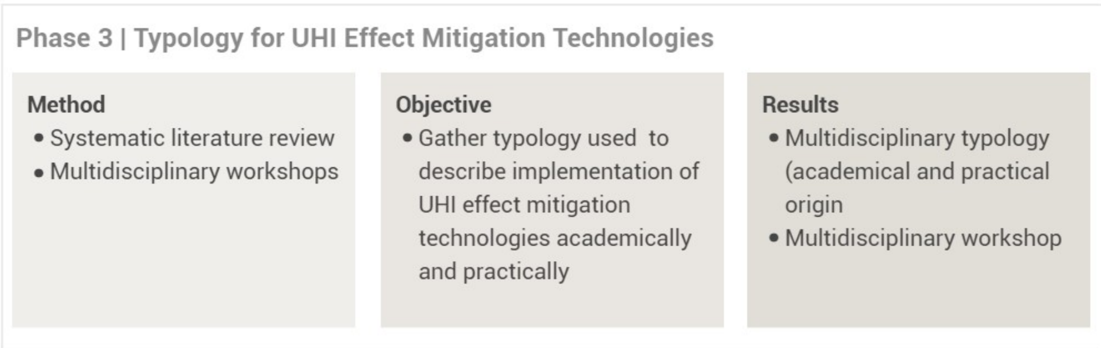


Figure 6.3: Illustration of the Third Framework Phase. This figure comprehensively depicts the applied methodology, the primary objective, and the central outcomes achieved during the execution of the initial framework phase.

6.1.4. Interface Conceptualization

The results of the interface conceptualisation phase aimed to achieve two primary objectives: organising research knowledge and proposing an effective format for multidisciplinary knowledge integration and dissemination. It's important to underscore that the presented interface is a conceptual representation that aligns with the study's goals rather than a fully realized product. This section, briefly restating the implications of the interface results, is followed by an elaboration on the validation process and a comparison analysis with currently available tools for UHI effect mitigation.

The developed interface concept enhances multidisciplinary knowledge integration and dissemination in several ways. Firstly, it promotes open access, encouraging a broad user base and facilitating widespread content distribution while allowing continuous improvements through user feedback. Moreover, it supports the integration of new research results, including ongoing Heat Square research, making it accessible to a broad audience.

Secondly, the interface's content is user-centric, structured by topic and detail level for personalised engagement, differentiating it from traditional formats like reports and books [Özerol et al., 2020]. It accommodates an expanding array of technologies, enabling comprehensive technology comparisons.

Furthermore, the interface fosters research initiation and direction by enabling users to identify and communicate missing information, leading to new research activities presented alongside ongoing research.

Lastly, it benefits technology developers by promoting their innovations, providing essential information for practical assessment, facilitating user feedback, enabling new research proposals, and offering insights into information demand and technology comparisons.

Interface validation

The interface underwent validation through end-user experiences conducted in August and September 2023. Insights from these experiences revealed that researchers (tool validation, August 30, 2023) found the presentation of new research opportunities valuable for understanding existing knowledge gaps. The comprehensive display of these gaps was deemed an efficient way to initiate research, eliminating the need for researchers to identify gaps and formulate queries. Additionally, the direct integration of ongoing Heat Square research to validate interface content was communicated as a strong feature.

As per feedback from TGV as platform manager (tool validation, August 18, 2023), the interface's strengths lie in its effective integration of knowledge related to the innovations tested at the Heat Square. Instead of dispersing information across individual innovation websites and research reports, the interface consolidates these elements into a unified platform. Additionally, the capacity for various Heat Square stakeholders, including developers, researchers, students, and municipal advisors, to pose questions was appreciated. This feature helps identify unanswered questions and potential research initiatives for TGV as a research facility to pursue. However, concerns were raised regarding the interface's ownership and the feasibility of developing and maintaining it as an open-access resource.

Finally, a workshop participant (tool validation, August 16, 2023), an Urban Designer who also moderated the PosadMaxwan integration session, expressed high appreciation for two key interface features: structured information presentation and technology comparison. It was highlighted that the clear topic clustering facilitated easy navigation within the interface. Furthermore, the value of presenting information at different levels of detail was emphasised, explaining that "this flexibility is beneficial during various stages of the design and implementation process". For example, brainstorming sessions benefit from concise, high-level information, while detailed designs require more in-depth data. Additionally, comprehensively comparing technologies based on specific topics of interest was deemed highly convenient for both the design process and multidisciplinary knowledge integration sessions. However, it was communicated that comparison option "A" of this comparison feature is assumed not to be used in practice as this would require too much time for complete comparison compared to the "B" option.

Comparative Analysis: Interface Concept Versus Existing Tools

The comparative analysis of the interface concept as a tool for climate adaptation and mitigation measures is based on the work of Hartog [2023]. This research investigates the relationship between tools and climate adaptation measures in the Netherlands over the past two decades. The findings are based on interviews with project leaders, consultants, designers, specialists, policy officers, housing corporations, and architects in both private and public sectors. Key findings of this research allow for comparison with the developed interface concept and its placement in the context of existing tools within the field of UHI effect mitigation.

According to Hartog [2023] a significant gap emerged in assessing available tools, including those catalogued in the national knowledge portal "Kennisportaal Klimaatadaptatie" comprising over 125 climate adaptation tools and those recommended by the interviewees. Notably, there is a shortage of tools that specifically address heat-related issues. This gap is underscored by the relatively recent emergence of heat-related problems in the Netherlands, resulting in a shortage of tools, knowledge, and guidance for effective mitigation and adaptation measures. Nevertheless, the growing importance of addressing these issues, as indicated by Garssen et al. [2005], has heightened the demand for tools that cater to heat-related challenges [Hartog, 2023] (p.13). Furthermore, observation revealed that the predominant approach to heat mitigation measures in the past two decades primarily centred on the introduction of vegetation for cooling purposes [Hartog, 2023] (p.36), which is in line with what was presented by Aleksandrowicz et al. [2017]. However, available tools lack adequate guidance and knowledge for these measures. In response to these gaps, the developed interface concept addresses heat-related challenges and offers comprehensive knowledge and guidance for implementing various technologies focussed on vegetation (Boomveer) and beyond.

Secondly, Hartog [2023] concludes that the current tools do not contribute to more climate adaptation measures being implemented due to them not providing desired insights on the measures' costs, maintenance and citizen involvement. Where current tools fail to provide insight into financial sources required to implement and maintain measures [Hartog, 2023] (p.38), the developed interface provides a comprehensive overview of costs related to the technology. This includes, among others, the Total Costs of Ownership (TCO) over the entire technology life cycle, installation costs, integral management costs, product price, and future perspectives on how these costs are assumed to change over the technology's life span. Furthermore, the interface provides information on maintaining a heat mitigation measure. It describes what maintenance is required and provides knowledge on how maintenance should be performed, who is responsible for maintenance, and the frequency of maintenance, including annual fluctuations. According to Kourtis and Tsihrintzis [2021] and Belčáková et al. [2019], this is currently not described in the literature nor made available through tools. The interviewees within the research performed by Hartog [2023] confirm this by arguing for a desperate need to fill this gap (p.39), something the developed interface aids in. Another aspect impeding the positive contribution of tools to mitigation measures is the lack of citizen involvement. Their perspective on mitigation measures must validate whether it would be accepted and perceived as intended. Where currently available tools are underdeveloped on this feature, the typology clusters in the topic "Social" extensively encompass such information formulated through typologies such as "Social acceptance", "Societal impact", "Community engagement", and "Awareness and Acceptance".

Another difference between the developed interface concept and existing tools is the range of knowledge presented. According to the reviewed tools in the research of Hartog [2023], most tools provide specific knowledge as a stand-alone product developed for one particular audience without interconnection with other tools. They present information on a single aspect of the mitigation measure, for instance, reports on performance, political instruments, vision documents and vulnerability identification. In contrast, the developed interface presents knowledge on ten topics simultaneously, providing broader knowledge integration. However, according to Hartog, the developed concept is underdeveloped regarding linkage to other tools, which should be integrated when fully developed.

Lastly, final remarks on the developed interface are highlighted by Hartog through interacting with the tool itself (August 30, 2023). According to Hartog, the concept's distinguishing feature lies in its adaptability for various intended end-users, making it versatile in its applications. Additionally, it was highlighted that identifying the remaining knowledge gaps in the interface concept is very convenient to support the initiation of streamlined research initiatives.

Ultimately, based on the expertise on climate adaptation tools, Hartog provided a list of improvements that could be made to the interface concept

- **Connection to other tools:** The interface is not connected to other available tools such as heat stress calculators and vulnerability maps. This is something missing in the interface and is recommended to be improved on to provide users with a more comprehensive tool that helps to identify and quantify the problem and provides knowledge and guidance for the solution.
- **Most cited content:** The quantitative overview of the most cited content, which is currently exclusive to innovation developers, should be extended to the research group. This addition offers valuable insights into the most requested information and helps prioritise new research activities.
- **Technology comparison:** The technology comparison feature could be improved. Option "A" would be more user-friendly to enable direct pop-up displays of information on other technologies for a specific content topic rather than requiring users to select topics and wait for a final overview. For option "B," enhancements could enable users to compare multiple topics simultaneously and assign significance to each topic based on their expertise. This would enable multi-criteria analysis comparisons, making the tool more versatile.
- **Navigation improvement:** Navigation improvements could streamline the user experience, as the current version involves excessive clicking to access all content. Enhancements might involve implementing search bars and drop-down menus facilitating swift transitions to other web pages for improved user efficiency.

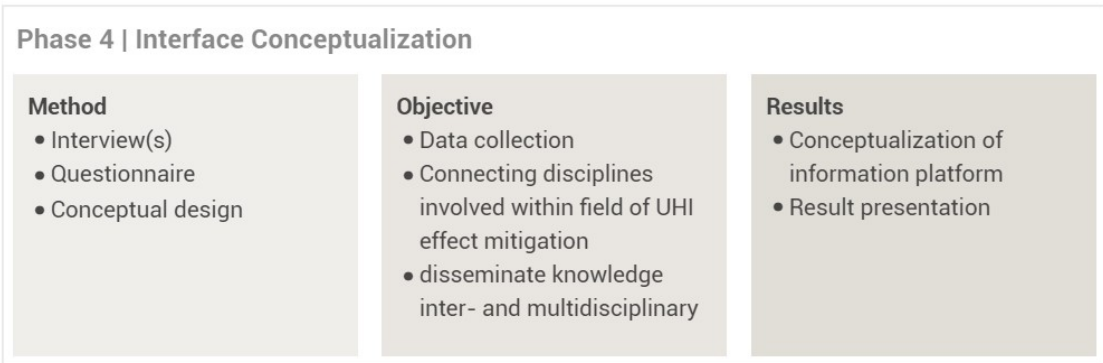


Figure 6.4: Illustration of the Fourth and Final Framework Phase. This figure comprehensively depicts the applied methodology, the primary objective, and the central outcomes achieved during the execution of the initial framework phase.

6.2. Implication of Framework

This section discusses the implications of the overarching framework developed in this study, emphasising its applicability within the research scope, particularly at the Heat Square within TGV. Additionally, it considers the framework's relevance in a broader context.

6.2.1. Heat Square Implications

Within the scope of the Heat Square, the framework provides a systematic approach that applies to various technologies at any stage of development, resulting in (i) the identification of required information for its assessment and implementation, (ii) the collection of knowledge in response to these requirements, and (iii) the integration of this knowledge into an accessible platform that facilitates knowledge sharing to numerous users and disciplines.

These results contribute to the context of the Heat Square in numerous ways. Firstly, they offer a qualitative description of the cooling hypotheses associated with the integrated Heat Square design, encompassing both the synergies between technologies and the individual contributions of each integrated technology. Before this research, such a comprehensive description was lacking, resulting in a gap in available knowledge and a lack of clarity regarding the hypotheses that needed validation through ongoing and new research efforts at this facility.

Secondly, this framework has identified the information requirements for assessing and implementing the technologies tested at the Heat Square and presented these through typologies. These typology results are concurrently developed based on literature and multidisciplinary workshops, including experts, making it comprehensive and robust. Transforming these typologies into the questionnaire format has effectively generated knowledge in response to these information requirements. On the other hand, typologies remaining "unanswered" provide insight into information requirements that still need answering, which contributes to effectively directing new research. Furthermore, these typologies are developed on- and therefore contain broad applicability to various technology types, supporting quick tailoring of questionnaires to other technologies and allowing for rapid knowledge expansion of all technologies tested at the Heat Square.

Moreover, if developed fully, the interface concept provides a convenient knowledge integration platform of TGV for the technologies tested at the Heat Square. This consolidates existing knowledge, dispersed over various sources, including research reports and webpages, and integrates newly conducted research results from the Heat Square. This integration facilitates efficient knowledge dissemination and contributes to the presented content's validation. As research activities at the Heat Square progress, this ongoing interaction can further enhance the interface.

Lastly, the envisioned interface concept facilitates linkage among disciplines engaged in UHI mitigation, especially relevant to the Heat Square domain where developers, researchers, municipality officers and more converge. Users from diverse disciplines can continuously contribute to improving the tool and expanding information requirements by providing feedback and raising questions. This enables the emergence of new typology results without the need for full framework performance, streamlining the expansion process while maintaining convenience.

6.2.2. Broader context implications

The implications of the research findings extend beyond the immediate scope, bearing significance for the broader field of UHI effect mitigation. In contrast to prevailing methods, this framework adopts a co-production approach involving diverse disciplines, specifically tailored to address the practical informational requirements for assessing and implementing innovations. With that, the framework provides information on various aspects such as required financial resources, maintenance protocols, and public acceptance, something that is currently lacking Hartog [2023]. Furthermore, the framework responds to the identified scarcity of implementation guidance Aleksandrowicz et al. [2017]; Oliveira et al. [2020] by providing knowledge on various topics rather than conventional information that primarily focuses on performance metrics Hoffmann et al. [2017]; Qi et al. [2020]. Additionally, the designed accessibility of presented information, intended to be inclusive irrespective of background expertise, aligns with the recommendations of Lee and Kim [2022], Wang et al. [2021], and Eliasson [2000] to promote multidisciplinary collaboration in addressing the complex nature of UHI effect mitigation.

The framework's phases have a general nature, making them applicable to various innovative technologies and different contexts, such as addressing upcoming urban climate issues like drought, water scarcity, and pluvial flooding. This adaptability results in the general character of the developed typology, including factors like costs and maintenance, which can be applied to any innovation, regardless of the specific context. This versatility ensures the framework's broad applicability and promotes the integration of technologies beyond the scope of the Heat Square. Subsequently, the inclusion of more technologies will contribute to improving the developed interface. As the platform accommodates more technologies, its capacity to compare, analyse, and evaluate technology alternatives is enhanced, facilitating the exploration of synergistic effects and fostering integrated designs. This iterative enhancement elevates the platform's accuracy, credibility, and efficacy, encouraging its adoption and sustaining expansion.

Lastly, the research outcomes contribute to the technology comprehensiveness and climatological knowledge gap claims by focussing on an integral design within the Dutch context. Although this trait did not form the predominant focus of this research, the outcomes do contribute to the expansion of the Dutch-specific research applicability and acknowledge synergistic design potentials advocated of high importance [Echevarría Icaza et al., 2016; Santamouris and Kolokotsa, 2016; Deilami et al., 2018].

6.3. Limitations

Despite the research's implications outlined earlier, several limitations warrant attention:

The comprehensive framework, including the concept interface, has been fully implemented for a single innovation. However, while the assumption is that it can be conveniently expanded based on the completed framework elements of three other technologies, this expansion still needs validation. Currently, this limitation restricts the platform's ability to accommodate multiple technologies, compare them, and conduct synergistic analyses.

The typology results are not ranked in significance leading to the absence of insight into which typologies are most important.

The typology data derived from the workshop-based approach contains limitations. The urban design framework consulted for discipline identification lacks comprehensive guidance, resulting in the absence of disciplines such as maintenance, management, and contracting during the workshop sessions. This exclusion affects the completeness of the dataset. Additionally, the data analysis revealed a bias towards specific disciplines in the research outcomes. This, coupled with the chosen saturation point, emphasises this limitation, implying that conducting additional focus group sessions with the missing disciplines could improve the robustness and comprehensiveness of the data.

Data processing introduces errors due to raw data format, language discrepancies, and interpretation of definitions. Efforts to minimise errors via tools like ChatGPT mitigate impact but still have limitations, warranting acknowledgement.

The interview results from the innovation representative responding to the typology may be influenced by internal incentives, potentially impacting their credibility. The absence of validation phases involving external sources further obscures the information's validity, limiting its overall reliability. Additionally, due to time constraints in this research, only partial responses to the typology have been obtained, and cross-validation through questionnaire performance has not been executed. This leads to incomplete content, omitting topics like "Synergy," "Social," "Governmental," and "Impact & Vulnerability", and introduces potential biases in the interpretation and description of the interviewee's responses. However, the conceptual nature of the interface, rather than a fully developed product, mitigates the impact of these limitations, with opportunities for addressing them during the interface's development.

Lastly, the acquired hypotheses regarding the cooling mechanisms of the integral design as well as the individual technology components solely focus on cooling via evaporation, transpiration and initiation of micro-circulation and, with that, neglect information on essential other parameters such as albedo effect and emissivity.

6.4. Recommendations for Further Research

Based on the key findings and research limitations, several recommendations emerge, offering potential directions for further research, expansion, and practical implementation in the field of UHI effect mitigation.

1. Fully implement the developed framework on other innovative technologies within the research scope, particularly focusing on the latter two phases. This will validate the framework's applicability, enhance knowledge integration, and maximise the comparative and

synergistic potential of the informative platform. Subsequently, apply the full framework to innovative technologies outside the initial research scope.

2. Enhance the credibility of the presented information by validating and linking it to relevant literature and ongoing research activities. Leveraging research efforts at TGV for this purpose, especially by directly implementing research outcomes for validation, is recommended.

3. Consider utilising a questionnaire-based approach in the concluding phase of the framework. This approach offers efficient data collection and information validation instead of in-person interviews, which require extensive time and resources. Implementing data collection exclusively through questionnaires streamlines the process, promotes researcher independence, and allows for parallel completion by distinct innovation representatives.

4. Initiate the development of a fully functioning interface to enable end-users to provide feedback. This feedback will expand the typology results, potentially reducing the need for repeated framework iterations and saving time and resources. However, ensure the efficiency of the conceptual version before advancing further in development while considering previous recommendations.

7 Conclusion

The central objective of this research is to foster multidisciplinary knowledge integration and dissemination in the field of UHI effect mitigation. To achieve this, a systematic framework was developed, comprising four distinct phases to identify, gather, present and disseminate knowledge pertaining to UHI effect mitigation. This research adopts a multi-method approach emphasising multidisciplinary involvement and comprehensive knowledge presentation. The conclusions presented in the following sections address the stated subquestions in sequential order. Ultimately, these conclusions converge in answering the main research question of this study *"How can Urban Heat Island mitigation knowledge be gathered, described and distributed comprehensively using multidisciplinary typology?"*.

7.1. Concluding Subquestions

The Heat Square design aims to convert incoming energy into latent heat fluxes through evapotranspiration and subsequently remove these fluxes from the designated area by inducing airflow. The combination of multiple innovations in a synergetic design is hypothesized to create these cooling effects, which is concluded as unique in the field of UHI mitigation solutions. Out of the five integrated technologies, all are hypothesized to contribute to cooling via evapotranspiration, whilst only the "Boomveer" innovation is hypothesized to contribute to both cooling pathways. Furthermore, it is concluded that this innovation, with its above-ground root system, is hypothesized to provide enhanced cooling via evaporation of water from the substrate and transpiration due to improved tree health. Moreover, the contribution to stimulating microcirculation is concluded to arise from the checker-board shadow pattern cast by the tree. This happens because the pattern affects the ground temperature, which, in turn, influences the nearby air temperature. These temperature variations lead to changes in air pressure, promoting local air circulation. Although the answered typology results support these hypotheses, they too highlight the pivotal role of irrigation required for the health of the tree and thus the validity of the hypotheses.

Concerning the second stated subquestion, no unambiguous conclusion can be drawn about which disciplines are involved in urban development processes. The systematic literature review concludes that the urban design process is iterative, with internal feedback loops between distinct phases, encompassing conceptualization, solution generation, evaluation, realization, implementation, and monitoring. Although the importance of multidisciplinary expertise is repeatedly advocated for, no definitive conclusion could be drawn to the disciplines attributed to these phases. Stakeholder identification and engagement are part of the iterative cycle of this process and, therefore, cannot be standardized. Therefore the the disciplines involved with urban development processes vary from case to case encompassing a broad range. Although a systematic procedure to perform stakeholder identification is concluded by the key results, this is not performed within the scope of this research. Therefore, the lack of a comprehensive overview of involved stakeholders caused a lack of guidance in participant selection for the later conducted workshops, albeit leading to the included disciplines being unevenly distributed, incomplete and not tailored to the case of interest central in this research.

The typology of UHI effect mitigation technologies has emerged as a pivotal instrument for facilitating multidisciplinary knowledge integration as current formats (i) require much time and resources, albeit limited in being conducted on and applicable to (new) technologies that are yet described; (ii) are predominantly focussed on performance, albeit neglecting other essential topics; and (iii) presents information hierarchically, albeit not allowing for case-specific tailoring of information. Arising from the typology results, it is concluded that a substantial convergence between the typologies derived from literature and those derived from the workshop session with experts involved with the practical implementation of UHI effect mitigation technologies in the urban context. This is evident from the considerable overlap in data entries resulting from the concurrent approaches and, in particular, the alignment of definitions assigned to the typologies, which concluded that fewer than 20% (n = 15) of the literature-based typologies were not acquired through the workshop-based approach. Despite this, the amalgamation of literature-derived and workshop-derived data does enrich the robustness and comprehensiveness of the compiled typology as presented that merging of the literature-based results to the workshop-based results added 23% new typologies. Especially the specificness of the workshop-based typologies was concluded to be different from the literature-based typologies and contributed to the comprehensiveness of the data. Moreover, it is concluded that the typology data acquired through the workshops exhibits a notably higher standard deviation regarding topic representation than the literature-based data. This observation can be attributed to the limitation above in participant selection, accentuating the interconnectivity within the framework where limitations cascade into sequential framework phases. The impact of this limitation, which only affected the outcomes of the workshop-based approach, was mitigated by conducting the concurrent literature-based approach, concluding its value in this process.

Research outcomes to the final stated subquestion of this research hold more of a suggestive character. As the knowledge presentation is encompassed in conceptualising an informative interface, further research is required to conclude its functionality. However, the following conclusions can be drawn concerning the state sub-research question. The developed interface concept enhances multidisciplinary knowledge integration and dissemination by promoting open access, user-centric content, and integration of new research results, including ongoing Heat Square research. Furthermore, the content does not require any pre-knowledge, is presented at various levels of detail and encompasses multiple topics converged into a single platform. Moreover, validating the interface through end-user experiences highlighted its value in identifying research gaps, consolidating knowledge, and facilitating stakeholder communication. Researchers appreciated the presentation of new research opportunities, while the intended platform manager found it effective for integrating knowledge related to innovations tested at the Heat Square. Lastly, when contrasted with the existing tools in the field of UHI effect mitigation, which frequently lack comprehensive guidance for addressing heat-related challenges and offer limited insights into the costs, maintenance requirements, and citizen involvement associated with mitigation measures, the developed interface concept contributes to solving this gap. Unlike prevailing tools, which often provide narrowly tailored knowledge as isolated products aimed at specific end-users, the developed interface concept offers broader knowledge integration encompassing ten topics.

7.2. Broader Context Conclusions

Beyond the Heat Square, the implications of this research extend to the broader field of UHI mitigation. The co-production approach adopted in the framework represents a departure from conventional methods, addressing the need for practical implementation guidance highlighted in previous studies. The framework's accessibility and inclusivity, irrespective of disciplinary expertise and the generalizability of its phases, foster usability by any discipline and its performance on a wide range of technologies. Even so, it can be concluded that due to overlap in typology for technologies, the framework performance can build on previous outcomes and, therefore, is expected to become increasingly more effective. As the framework evolves iteratively, its capacity for accurately analysing and evaluating technology alternatives grows, enhancing its credibility and adoption potential.

7.3. Concluding Statement

In conclusion, the framework developed in this study enables the gathering, description, and dissemination of UHI mitigation knowledge using a multidisciplinary typology. Knowledge collection is facilitated through the completion of the typology questionnaire and the formulation of hypotheses for technologies with evolving knowledge. Subsequently, the interface concept serves as a platform for conveying and distributing this knowledge, covering a broad spectrum of ten topics and providing multiple levels of detail. Moreover, the interface's adaptability to diverse end-users suggests its potential to enhance the collection, description, and distribution of knowledge, driven by valuable end-user feedback and ongoing interface development.

The efficacy of this framework is rooted in its distinct phases, each yielding valuable individual outcomes that collectively address the central research inquiry. While certain limitations have an impact on the credibility and comprehensiveness of the results, these findings result from a mixed-method approach that combines academic literature and in-field expertise. Consequently, the transparent delineation of these approaches contextualizes these limitations, enabling a more nuanced assessment of their significance. Additionally, the recommendations for future research are positioned to facilitate convenient and practical implementation, thus contributing to the resolution of these limitations.

The framework sets forth a promising trajectory for advancing UHI effect mitigation efforts within specific projects like the Heat Square and across broader contexts. Its comprehensive and multidisciplinary approach, coupled with its adaptability, substantially contributes to knowledge integration, fosters multidisciplinary collaboration, guides technology implementation, informs decision-making, and highlights persistent knowledge gaps. Concerning the ongoing and projected increasing significance of challenges posed by UHI effects, this framework emerges as a robust and adaptable approach to realizing effective mitigation strategies, ultimately fostering urban environments that are more habitable and resilient under the effects of climate change.

Bibliography

(2023). Transverso - Translation into English - Examples Spanish | Reverso context.

Aiman, M. Q. (2021). Review and comparative study of decision support tools for the mitigation of urban heat stress. *Climate*, 9(6):102. Copyright - © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/). Notwithstanding the ProQuest Terms and Conditions, you may use this content in accordance with the terms of the License; Last updated - 2022-07-01.

Akbari, H., Cartalis, C., Kolokotsa, D., Muscio, A., Pisello, A. L., Rossi, F., Santamouris, M., Synnefa, A., Wong, N. H., and Zinzi, M. (2016). Local climate change and urban heat island mitigation techniques - the state of the art. *Journal of Civil Engineering and Management*, 22(1):1 – 16. Cited by: 282; All Open Access, Green Open Access, Hybrid Gold Open Access.

Alcoforado, M.-J., Andrade, H., Lopes, A., and Vasconcelos, J. (2009). Application of climatic guidelines to urban planning: The example of lisbon (portugal). *Landscape and Urban Planning*, 90(1):56–65.

Aleksandrowicz, O., Vuckovic, M., Kiesel, K., and Mahdavi, A. (2017). Current trends in urban heat island mitigation research: Observations based on a comprehensive research repository. *Urban Climate*, 21:1–26.

Arellano, B., Roca, J., and Arenas, R. (2018). Planning and urban climate: the example of the metropolitan area of barcelona. page 3.

Arrau, C. P. and Peña, M. A. (2010). The urban heat island (uhi) effect. *Urban Heat Islands (UHIs)*.

ATLAS.ti Scientific Software Development GmbH (2023). Atlas.ti mac (version 23.2.1). Qualitative data analysis software.

Attema, J., Bakker, A., Beersma, J., Bessembinder, J., Boers, R., Brandsma, T., van den Brink, H., Drijfhout, S., Eskes, H., Haarsma, R., et al. (2014). Knmi'14: Climate change scenarios for the 21st century–a netherlands perspective. *KNMI: De Bilt, The Netherlands*.

Barreira, E., Almeida, R., and Simões, M. J. (2021). Emissivity of building materials for infrared measurements. *Sensors*, 21(6):1961.

Belčáková, I., Świąder, M., and Bartyna-Zielińska, M. (2019). The green infrastructure in cities as a tool for climate change adaptation and mitigation: Slovakian and polish experiences. *Atmosphere*, 10(9).

Bergman, T. L., DeWitt, D. P., Incropera, F. P., and Lavine, A. S. (2017). *Incropera's Principles of Heat and Mass Transfer*.

Boland, B., Charchenko, E., Knupfer, S., Sahdev, S., Farhad, N., Garg, S., and Huxley, R. (2021). Focused adaptation - a strategic approach to climate adaptation in cities. Technical report.

Bosch, P., Broeke, t. H., Gjaltema, J., Pasztor, A., and Rovers, V. (2013). De synergie van stedelijke klimaatadaptatie en - mitigate maatregelen; een vijftal maatregelen uitgewerkt voor rotterdam. Technical Report KVK 102/2013.

Bryman, A. (2012). *Social Research Methods*. Oxford University Press, Oxford, gb, 4 edition.

Butt, A. N. and Dimitrijević, B. (2022). Multidisciplinary and transdisciplinary collaboration in nature-based design of sustainable architecture and urbanism. *Sustainability*, 14(16).

Campbell, D. T. and Fiske, D. W. (1959). Convergent and discriminant validation by the multitrait-multimethod matrix. *Psychological Bulletin*, 56(2):81–105.

Chakraborty, T., Hsu, A., Manya, D., and Sheriff, G. (2019). Disproportionately higher exposure to urban heat in lower-income neighborhoods: a multi-city perspective. *Environmental Research Letters*, 14(10):105003.

Cheng, Y., Niu, J., and Gao, N. (2012). Thermal comfort models: A review and numerical investigation. *Building and Environment*, 47:13–22.

Cooper, R. and Boyko, C. (2010). How to design a city in five easy steps: exploring vivacity2020's process and tools for urban design decision making? *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*, 3(3):253–273.

Corburn, J. (2009). Cities, climate change and urban heat island mitigation: Localising global environmental science. *Urban Studies*, 46:413–427.

Cortes Arevalo, V. J., den Haan, R.-J., Berends, K. D., Baart, F., van der Voort, M., and Hulscher, S. J. (2023). Drivers and barriers to knowledge exchange through an envisioned online platform for transdisciplinary research projects. *Environmental Science Policy*, 147:201–214.

de Groot-Reichwein, M., Lammeren, R., and Goosen, H. (2018). Urban heat indicator map for climate adaptation planning. *Mitig Adapt Strateg Glob Change*, 23:169–185.

Deilami, K., Kamruzzaman, M., and Liu, Y. (2018). Urban heat island effect: A systematic review of spatio-temporal factors, data, methods, and mitigation measures. *International Journal of Applied Earth Observation and Geoinformation*, 67:30–42.

Department of Infrastructure & Regional Development Australia (Producer) (2013). Urban design model process: An urban design protocol for australian cities.

Dias, N., Curwell, S., and Bichard, E. (2014). The current approach of urban design, its implications for sustainable urban development. *Procedia Economics and Finance*, 18:497–504. 4th International Conference on Building Resilience, Incorporating the 3rd Annual Conference of the ANDROID Disaster Resilience Network, 8th – 11th September 2014, Salford Quays, United Kingdom.

Dirksen, M., Ronda, R., Theeuwes, N., and Pagani, G. (2019). Sky view factor calculations and its application in urban heat island studies. *Urban Climate*, 30:100498.

Döpp, S., Klok, L., Janssen, S., Jacobs, C., Heusinkveld, B., and Klemm, W. (2011). Kennismontage hitte en klimaat in de stad.

D'Este, P., Iammarino, S., Savona, M., and von Tunzelmann, N. (2012). What hampers innovation? revealed barriers versus deterring barriers. *Research Policy*, 41(2):482–488.

Echevarría Icaza, L., van der Hoeven, F., and van den Dobbelsteen, A. (2016). *The Urban Heat Island Effect in Dutch City Centres: Identifying Relevant Indicators and First Explorations*, pages 123–160. Climate Change Management. Springer Science+Business Media.

Echevarría Icaza, L., van der Hoeven, F., and van den Dobbelsteen, A. (2016). the urban heat island effect in dutch city centres: Identifying relevant indicators and first explorations. *Climate Change Management*, pages 123–160. cited By 6.

EEA (2020). *The European environment : state and outlook 2020 : knowledge for transition to a sustainable Europe*. Publications Office.

Eliasson, I. (2000). The use of climate knowledge in urban planning. *Landscape and Urban Planning*, 48(1):31–44.

EPA (2022). Heat Island Impacts.

EURO2021 and Delft, T. U. (2021). MANIFEST: A NEW NATURE BASED URBAN BUILDING STANDARD.

FieldFactors (2023). Testing bluebloqs loop at hitteplein, technical university of delft. accessed: 20.04.2023.

Fuladlu, K., Riza, M., and Ilkan, M. (2018). The effect of rapid urbanization on the physical modification of urban area.

Garssen, J., Harmsen, C., and De Beer, J. (2005). The effect of the summer 2003 heat wave on mortality in the Netherlands. *Eurosurveillance*, 10(7):13–14.

Geng, X., Zhang, D., Li, C., Yuan, Y., Yu, Z., and Wang, X. (2023). Impacts of climatic zones on urban heat island: Spatiotemporal variations, trends, and drivers in china from 2001–2020. *Sustainable Cities and Society*, 89:104303.

Giguère, M. (2009). *Literature review of urban heat island mitigation strategies*. desLibris.

Goodman, L. A. (1961). Snowball sampling. *Annals of Mathematical Statistics*, 32(1):148–170.

Gunawardena, K., Wells, M., and Kershaw, T. (2017). Utilising green and bluespace to mitigate urban heat island intensity. *Science of The Total Environment*, 584-585:1040–1055.

Hall, M. R. (2010). *Materials for Energy Efficiency and Thermal Comfort in Buildings*. Woodhead Pub Limited.

Hall, R. (2020). *Mixing methods in social research*. SAGE Publications Limited.

Hartog, N. (2023). Climate adaptation: Relating policy, tools, and measures for the public and private sector. Master's thesis, Delft University of Technology.

Haselip, J., Narkeviciute, R., Rogat, J., and Traerup, S. (2019). *TNA Step by Step. A guidebook for countries conducting a Technology Needs Assessment and ACtion Plan*.

Heaviside, C., Macintyre, H., and Vardoulakis, S. (2017). The urban heat island: implications for health in a changing environment. *Current environmental health reports*, 4:296–305.

Hoelscher, M.-T., Nehls, T., Jänicke, B., and Wessolek, G. (2016). Quantifying cooling effects of facade greening: Shading, transpiration and insulation. *Energy and Buildings*, 114:283–290. SI: Countermeasures to Urban Heat Island.

Hoffmann, S., Pohl, C., and Hering, J. G. (2017). Methods and procedures of transdisciplinary knowledge integration: empirical insights from four thematic synthesis processes. *Ecology and Society*, 22(1).

Hovland, I. (2005). *Successful Communication - A Toolkit for Researchers and Civil Society Organisations*. Research and Policy in Development Programme, Overseas Development Institute.

IPCC (2022). *Summary for Policymakers*, page 1–24. Cambridge University Press.

Kibria, M. and Van Oosterom, P. (2008). Functionalities of geo-virtual environments to visualize urban projects. Faculty of OTB Research Institute for the Built Environment. GIS Technology department. Programme: GIMA.

Kleerekoper, L., van Esch, M., and Salcedo, T. B. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Resources, Conservation and Recycling*, 64:30–38. Climate Proofing Cities.

Klok, E. L. and Kluck, J. J. (2018). Reasons to adapt to urban heat (in the netherlands). *Urban Climate*, 23:342–351. ICUC9: The 9th International Conference on Urban Climate.

Koers (2023). Halfverhardingen. accessed: 20.04.2023.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., and Rubel, F. (2006). World map of the köppen-geiger climate classification updated.

Kourtis, I. M. and Tsihrintzis, V. A. (2021). Adaptation of urban drainage networks to climate change: A review. *Science of The Total Environment*, 771:145431.

Kwon, Y. J. and Lee, D. K. (2019). Thermal comfort and longwave radiation over time in urban residential complexes. *Sustainability*, 11(8):2251.

Lai, D., Liu, W., Gan, T., Liu, K., and Chen, Q. (2019). A review of mitigating strategies to improve the thermal environment and thermal comfort in urban outdoor spaces. *Science of The Total Environment*, 661.

Lang, D. J., Wiek, A., Bergmann, M., and et al. (2012). Transdisciplinary research in sustainability science: practice, principles, and challenges. *Sustainability Science*, 7(Suppl 1):25–43.

Lawrence, M. G., Williams, S., Nanz, P., and Renn, O. (2022). Characteristics, Potentials, and Challenges of transdisciplinary research. *One earth*, 5(1):44–61.

Lee, S. and Kim, D. (2022). Multidisciplinary understanding of the urban heating problem and mitigation: A conceptual framework for urban planning. *International Journal of Environmental Research and Public Health*, 19(16).

Lee, Y., Fadhil, M., Mohanadoss, P., Zainon Noor, Z., Iwao, K., and Chelliapan, S. (2014). Overview of urban heat island (uhi) phenomenon towards human thermal comfort. *Environmental engineering and management journal*, 16.

Lowe, S. A. (2016). An energy and mortality impact assessment of the urban heat island in the us. *Environmental Impact Assessment Review*, 56:139–144.

Lucertini, G., Di Gisutino, G., dall'Omo, C., and Musco, F. (2022). An innovative climate adaptation planning process: ideal project. *Journal of environmental management*, 317:115–408.

Lähde, E. and Di Marino, M. (2019). Multidisciplinary collaboration and understanding of green infrastructure results from the cities of tampere, vantaa and jyväskylä (finland). *Urban Forestry Urban Greening*, 40:63–72. Urban green infrastructure – connecting people and nature for sustainable cities.

Mabry, P. L., Olster, D. H., Morgan, G. D., and Abrams, D. B. (2008). Interdisciplinarity and systems science to improve population health: A view from the nih office of behavioral and social sciences research. *American Journal of Preventive Medicine*, 35(2, Supplement):S211–S224. The Science of Team Science.

Mao, Y. (2022). Changing patterns of thermal behavior of concrete pavements in diurnal periods.

Masseck, T., Den Ouden, E., and Valkenburg, R. (2017). Smart urban spaces general roadmap - d5.2 report - timelines for the topics in smart urban spaces. Technical report.

Meehl, A. G. and Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21st century. *Science*, 305:994–997.

Mohammad Harmay, N. S. and Choi, M. (2022). Effects of heat waves on urban warming across different urban morphologies and climate zones. *Building and Environment*, 209:108677.

Nabielek, K. and Hamers, D. (2015). De stad verbeeld. Technical Report 1744. Report of Planbureau voor de Leefomgeving (PBL).

New Urban Standard (2023). Technologie + water voor gezond leven in de stad. accessed: 20.04.2023.

Nguyen, M. and Mougenot, C. (2022). A systematic review of empirical studies on multidisciplinary design collaboration: Findings, methods, and challenges. *Design Studies*, 81:101120.

Oke, T. (1988). The urban energy balance. *Progress in Physical Geography: Earth and Environment*, 12(4):471–508.

Oliveira, A. C. M., Machado, J. A. T., and Niza, S. (2020). Local climate zones in five southern European cities: An improved GIS-based classification method based on Copernicus data. *urban climate*, 33:100631.

OpenAI (2023). Chatgpt (august 3 version). Large language model.

Ortman, S. G., Lobo, J., and Smith, M. E. (2020). Cities: Complexity, theory and history. *PLOS ONE*, 15(12):1–24.

Ottelé, M. and Perini, K. (2017). Comparative experimental approach to investigate the thermal behaviour of vertical greened façades of buildings. *Ecological Engineering*, 108:152–161.

O'Malley, C., Piroozfar, P., Farr, E. R., and Pomponi, F. (2015). Urban heat island (uhi) mitigating strategies: A case-based comparative analysis. *Sustainable Cities and Society*, 19:222–235.

Peng, W., Yuan, X., Gao, W., Wang, R., and Chen, W. (2021). Assessment of urban cooling effect based on downscaled land surface temperature: A case study for fukuoka, japan. *Urban Climate*, 36:100790.

PosadMaxwan (2023). handbook on designing with/for vital soil in urban areas. Technical report. This research by design has been financially supported by the Creative Industries Fund NL and the municipality of Rotterdam.

Puig, D., Le Manceau, L. J., and Gregersen, L. E. (2021). *Technology Needs Assessments. Climate Technologies in an urban context*.

Qi, J., Ding, L., and Lim, S. (2020). Planning for cooler cities: A framework to support the selection of urban heat mitigation techniques. *Journal of Cleaner Production*, 275:122903.

Qi, J., Ding, L., and Lim, S. (2021). Toward cool cities and communities: A sensitivity analysis method to identify the key planning and design variables for urban heat mitigation techniques. *Sustainable Cities and Society*, 75:103377.

Qi, J., Ding, L., and Lim, S. (2022). A decision-making framework to support urban heat mitigation by local governments. *Resources, Conservation and Recycling*, 184:106420.

Rehan, R. M. (2016). Cool city as a sustainable example of heat island management case study of the coolest city in the world. *HBRC Journal*, 12(2):191–204.

Ritchie, H. and Roser, M. (2018). Urbanization. *Our World in Data*. https://ourworldindata.org/urbanization.

Rizwan, A. M., DENNIS, L. Y., and LIU, C. (2008). A review on the generation, determination and mitigation of urban heat island. *Journal of Environmental Sciences*, 20(1):120–128.

Rogat, J. (2015). *Identification and Engagement of Stakeholders in the TNA Process*. UNEP DTU Partnership.

Russo, S., Sillmann, J., and Fischer, E. M. (2015). Top ten european heatwaves since 1950 and their occurrence in the coming decades. *Environmental Research Letters*, 10(12):124003.

Salcedo Rahola, T. B., Oppen, P., and Mulder, K. (2009). Heat in the city - an inventory of knowledge and knowledge deficiencies regarding heat stress in dutch cities and options for its mitigation.

Santamouris, M. and Kolokotsa, D. (2016). *Urban climate mitigation techniques*. Routledge.

Spärck Jones, K. (1972). A statistical interpretation of term specificity and its application in retrieval. *Journal of Documentation*, 28(1):11–21.

Stache, E. E., Schilperoort, B. B., Ottele, M. M., and Jonkers, H. M. H. (2022). Comparative analysis in thermal behaviour of common urban building materials and vegetation and consequences for urban heat island effect. *BUILDING AND ENVIRONMENT*, 213.

Stewart, I. D. and Oke, T. R. (2012). Local climate zones for urban temperature studies. *Bulletin of the American Meteorological Society*, 93(12):1879–1900.

Terjesen, A. J. (2007). Phil 101-01, introduction to philosophy, fall 2007.

TGV (2022). The Green Village, fieldlab voor duurzame innovatie.

TGV (2023). Hitteplein.

The Urban Jungle Project (2023). We develop urban jungles for future-proof city climates. accessed: 20.04.2023.

Thompson, M. A., Owen, S., Lindsay, J. M., Leonard, G. S., and Cronin, S. J. (2017). Scientist and stakeholder perspectives of transdisciplinary research: Early attitudes, expectations, and tensions. *Environmental Science & Policy*, 74:30–39.

Tuzet, A. J. (2011). *Stomatal Conductance, Photosynthesis, and Transpiration, Modeling*, pages 855–858. Springer Netherlands, Dordrecht.

TyleSystems (2023). Trottoirtegels en klinkers met zoak techniek. accessed: 20.04.2023.

UN Habitat (2022). *World Cities Report 2022: Envisaging the Future of Cities*.

Wang, C., Wang, Z.-H., Kaloush, K. E., and Shacat, J. (2021). Perceptions of urban heat island mitigation and implementation strategies: survey and gap analysis. *Sustainable Cities and Society*, 66:102687.

Washburn, A. (2015). *The Nature of Urban Design*. Island Press.

Weather, T. G. H. and Data, C. (2023). World Climate Data.

Yamamoto, Y. (2006). Measures to mitigate urban heat islands. 2(18):65–83.

Özerol, G., Dolman, N., Bormann, H., Bressers, H., Lulofs, K., and Böge, M. (2020). Urban water management and climate change adaptation: A self-assessment study by seven midsize cities in the north sea region. *Sustainable Cities and Society*, 55:102066.

Appendix A. Logbook - Multidisciplinary workshops

1. Report - Workshop #0 (testing)

Date: 06/04/2023
Location: Campus Delft Univerisity of Technology

The first workshop, referred to by number zero (0), is initiated for testing and evaluation of the developed initial state of the workshop as described in the main document Chapter 4. Therefore, the main objective deviates from the overall aim of sequential workshops and is shifted towards critical reflection on the workshop process rather than the generation of results. Despite this, due to the attendance of participants from disciplines identified as being connected to and involved with urban heat mitigation, generated results are assumed to be viable for this research. Furthermore, it was considered important for this phase that the disciplinary background of the participants differs from one of the performing researchers to test the interdisciplinary applicability of the workshop. Lastly, the participants for this session were invited via a mutual network and on a fully voluntary basis. No direct connection between the researcher and the participants existed before this workshop, and no conflicts of interest were identified before or in retrospect to the session.

Participating disciplines

Three (3) participants attended the tryout session of the workshop. A general description of participants' professions or disciplines is presented in Table A1

Table A1: Participant overview of workshop session #0

Profession	Discipline	Number of participants
Academic	Environmental Technology & Design - Urbanism	1
Academic	Urban Design - Climate adaptation	1
Academic	Urban planning & Design - Urban climate planning	1

Workshop program

The following phases and associated steps present the intended workshop approach to be executed within the tryout version. For this session, a total duration of approximately one (1) hour was scheduled. The time indication per activity is indicated within the steps.

Phase 0 Before the session (+- 5 min)

Step 1 Before the workshop introduction, it will be explained that this session is intended as a tryout version of the workshop intended to be carried out throughout this research. Moreover, the participants will be told that participating in this session will be (anomalously) contributing to the research, and their evaluation will be used to improve on this workshop. Moreover, the participants will be explained that their critical evaluation of the workshop will be asked at the end of the session. Ultimately, once the overarching goal of the tryout session is presented, the participants' informed consent will be asked for.

Phase 1 | Program, Introduction & Context (10 - 15 min)

Step 1 | Workshop program: The intended program of the workshop session will be introduced to the participants. This program consists of an introduction (10 min), Brainstorm activity 1 (25 min), Brainstorm activity 2 (15 min), Round up & closing (5 - 10 min), and Post session evaluation (10 min). Accumulating to approximately 60 to 70 minutes.

Step 2 | Introduction: The overarching research topic this workshop is part of will be briefly introduced. Moreover, the general objective of this introduction is to transfer the importance and goal of this workshop to be developed and carried out. First, this research's relevance ('**Why**') and the context are, presented. The core theme (Urban heat Island effect mitigation technologies) will be explained, the prevailing research gaps this research aims to close will be presented, and the participants will be introduced to the solution pathways tested at the Heat Square at TGV. Next, the research approach ('**How**') will be presented and how this workshop fits within that approach, aiming to give the participants a clear idea of what this session contributes to. Lastly, the introduction is finalized with the task explanation ('**What**'), which will be elaborated on in the next phases.

Phase 2 | Brainstorm activity 1 (+-25 min)

Step 1 | Technology introduction: The participants will be introduced to one of the technologies tested in the design of the Heatsquare at TGV. For this session, the 'Boomveer' technology was selected based on the assumption that the required knowledge of the technology is the most convenient to transfer to the participants within a short presentation. The goal of this technology introduction is that the participants have a superficial but clear understanding of the assessed technology.

Step 2 | Brainstorm activity one explanation: The first Brainstorm activity task will now be introduced. The participants will be asked to come up with as many 'information aspects' that could be important for implementing the assessed technology within an urban environment. They will do so by writing sticky notes and placing them on bigger sheets of paper, which are divided into several pre-clustered domains: functional, social, governmental, design, economic, and other. To better understand this task, the facilitator will give multiple examples for each cluster. Important is that the examples are documented and extracted from the data collection.

Step 3 | Execution: The participants will be told that they can communicate with one another if that would help their thinking process. Then, before starting the 25 minutes for this activity, the participants will be asked if the activity is clear and whether they feel capable of performing the task based on the information that was given. If no additional explanation is required, the 25 minutes for this task can be started.

Phase 3 | Brainstorm activity 2 (+- 15 min)

Step 1 | Round up activity 1: The first brainstorm will naturally stop when the participants cannot generate new information or when the 25-minute point has been passed.

Step 2 | Brainstorm activity 2 explanation: The second Brainstorm activity will be presented to the participants. In this second phase, the objective is to rank the results of Brainstorm Activity 1 and place them in order of importance on the sheets where the most important aspects will be on the top of the sheet, and the least important on the bottom. An example will be provided to the participants and asked if, based on this explanation, they understand the activity and are able to carry out the task.

Step 3 | Execution: If the participants agree on understanding the task, the timer for 15 minutes will start.

Phase 4 | Evaluation (+- 10 min)

Step 1 | Round up: The workshop is rounded up and asked if the participants need more time for the asked tasks. If so they can be given additional time. They will too be asked if there are any comments on the workshop activities themselves. Lastly, it is of high importance that the facilitator will read through the results throughout the workshop to potentially ask for additional explanation on a generated information aspect and reduce the chance of unapplicable results.

Step 2 | Session evaluation: This tryout session will be ended with an open evaluation of the process. The participants will be asked to give critical feedback on the whole process. This feedback will be documented and used in the further development of the workshop.

Evaluation facilitator

The workshop has been performed according to the described program above up to phase 3. During the first brainstorming activity it became clear that, although the participants reported that the explanation and task were clear, more time was required. The discussion/process of writing down information aspects did not flourish right from the start. It took the participants some time to get the first aspects on the sheet. I let this process be for approximately the first 10 minutes. As the process of writing down information aspects (after approximately 10 aspects) stagnated, I tried to activate the discussion/thinking process by giving more examples. Again I gave the participants 10 minutes to work from this with the new examples I gave. However, this did not seem to be very effective as only 11 more information aspects were generated. For this situation, I prepared another approach to get the discussion started again by introducing them to a new technology (ZOAK tiles from Tilesystem) and asking about information aspects again. Only now I actively participated in the form of letting them call out aspects and me writing them down. This worked far better, and much more information aspects were called out. As this was effective, and the main goal of the workshop was to generate as much information aspects as possible, I decided to change the program and disregard the second phase of the workshop. This time I used to expand on the first phase with this new approach. After a total of 40 minutes, the discussion came to an end and I asked the participants if they would need more time for the generation of more results. The participants agreed on rounding up the session due to no more results were likely to be generated. Then the session ended according to the described fourth phase.

One of the issues raised during the session is the uncertainty as to which of the discussed technologies the results apply. As for now, the distinguishment has been made based on the results developed after the described introduction of the second technology. However, the generated results could potentially be applicable to the other discussed technology, hence introducing uncertainty within the collected data. As this information regarding the results is not collected, this introduces a point of discussion. For upcoming sessions, this uncertainty should be removed.

Received feedback

During the evaluation, the following points of feedback were provided:

- It was not completely to the participants for whom this workshop was developed, nor was it clear who the users of the end results of the research would be. Participants reported that if this had been more clear this would help them understand the context of the workshop better.
- The Urban Heat Island phenomenon could be explained more extensively.
- In retrospect it was not entirely clear if the participants were asked to generate the information aspect for only the introduced technology, or that the technology was only an example and they were asked to generate information aspects in a broader sense of technology.
- The participants reported that it would work better if the facilitator is the one who writes the sticky notes, and that the participants call out the information aspects. They argued that this would help to start a more open discussion/brainstorming environment.
- Participants reported that documenting what is 'meant' by each individual information aspect is crucial for the understanding of the results.
- More examples for the Brainstorm activity would help to give the participants a better understanding of what they need to do.

Points of improvement

The following workshops should at least be improved on:

- Better contextual information on the Urban Heat Island phenomenon, for whom this workshop is developed, and who the targeted group of interest is for the end results of this research.
- More reserved time for the first Brainstorm activity.
- More attention that the participants understand they are asked to provide information on the introduced technology.
- Let the facilitator write down the generated information aspects to stimulate a better plenary discussion.
- Provide more examples prior to the Brainstorm activities.

- It should be clear to which technology the results apply. This could be done by only discussing one (1) technology, or by letting the participants clarify the applicability of their generated results.

2. Report - Workshop #1

Date: 13/04/2023
Location: The Green Village

The workshop that is described in this section is the improved version based on the acquired evaluation as presented in Section 1. The workshop was included within the program of an event being hosted at TGV named 'Klimaat Kwartier Kennis Sessie'. The main theme of the event revolved around the climate resilience of cities within the domains of 'water' and 'heat'. Participants invited for this session originated from various disciplines as well as locations within the Netherlands which resulted in a diverse group of professionals of approximately fifty (50) to sixty (60) people. As this workshop was one of four 'breakout sessions' participants were asked to choose which activity appealed to them the most based on a short description given by the workshop facilitators. This resulted in a total of ten (10) voluntary participants contributing to the workshop session.

Participating disciplines

In total ten (10) participants attended this workshop. A general description of participants' professions or disciplines is presented in Table A2

Table A2: Participant overview of workshop session #1

Profession	Discipline	Number of participants
Government advisor	Climate adaptation in the urban environment	1
Advisor Municipal Health Service	Environment and Health	1
Entrepreneur	Climate adaptation solution in the urban environment	2
Policy officer	Water & Climate	2
Policy officer	Public space & Climate adaptation	1
Policy officer	Urban water management & Climate adaptation	1
Municipality director	Climate adaptation	1
Consultant/developer	Not known	1

Workshop program

On the basis of the received feedback on the tryout session of the workshop, the program is slightly adjusted. Additionally, the workshop is tailored to the specific event regarding its content and duration. The adjustments made to the described workshop program (Table 1) are clustered in the following points:

- **Phase 0 (+- 5) min** In contrast to the tryout session, the workshop carried out in this session purely focuses on the generation of the information aspects, rather than being used for evaluation purposes as well. Nevertheless, prior to the session, it will be explained that the results remain anonymous and informed consent will be asked.

- **Phase 1 (8-10 min):** The first phase is slightly shortened due to the available time for the session. No workshop program will be introduced since this version only exists of an introduction and a single brainstorming activity. The second step is slightly changed according to the received feedback. There will be more attention to explaining the Urban Heat Island phenomenon (with figures). Furthermore, it will be explicitly explained what the intention and goal of this workshop is, as well as, for whom the workshop is designed for and who the users of the end results of this research are. Lastly, less time will be reserved for the explanation of TGV and the activities on the Heatsquare, since it is assumed that the event as a whole will provide sufficient contextual information.

- **Phase 2 (25 min):** This session remains essentially unchanged regardless of the following points. The technology introduced to the participants will be the ZOAK tile. This is chosen to do so in line with the described **methodology**. Secondly, it will explicitly be explained that the participants are only expected to perform the tasks on the introduced technology only. This is to eliminate the confusion raised within the tryout session regarding this point. Lastly, the participants are asked to 'feel free' with respect to the method they apply to write down their results. I.e. they can write sticky notes themselves, but are too encouraged to openly discuss their thoughts with the other participants. This approach will be applied to stimulate the process of results being generated. Following that same objective, more results examples are provided to the participants which are actively written and put on the paper by the facilitator to 'show' the participants the process that is aimed for. Finally, after approximately fifteen (15) minutes the participants will be told that if they are not able to generate more results, they could look at the results being generated (by themselves or the other participants) and try to make them more specific. An example of this will be given using the general term 'costs' compared to specific terms such as 'maintenance costs', 'management costs', 'implementation costs', etc.
- **Phase 2 (open end)**: The session will be closed off with an open end. Five (5) minutes prior to the end of the reserved time is reached the facilitator will end the activity and ask the participants to give feedback on the workshop. As the end of this session is succeeded by an informal network event, these questions could lead to interesting conversations but are not intended to be part of the workshop.

Evaluation facilitator

The process of executing the workshop is deemed to be more successful based on the following arguments. The generation of information elements went more smoothly compared to the tryout session, hence leading to more results. Additionally, the participants indicated that the context of the workshop was completely clear and that they were able to perform the tasks efficiently after the explanation. Lastly, no points of improvement were indicated by the participants. Overall, I think the location being at the research area as well as the information presented during the overall event, significantly contributed to the participant's understanding of the discussed workshop theme. On top of that, based on the performance of the focus group, I would argue that the potential of the workshop was very much limited due to the available time.

Received feedback

The general feedback provided by the participants revolves around their agreement on the importance of interdisciplinary collaboration on the UHI mitigation strategies and the contribution of this research to that end.

Points of improvement

No real points of improvement will be incorporated within the sequential sessions as this session proved to be very successful. However, based on time availability the session should be expanded to reach its full potential. This expansion could be realized by either or both of the following points:

- Introduce more technologies that can be discussed using the same approach. The advantage of this expansion is that there is no need for contextual or task explanation. Nevertheless, there should be extra attention to assessing the generated results regarding their relevance to one or more of the discussed technologies. The use of different sticky note colours could be an option to make this distinguishment.
- The produced results could be ordered based on their significance. This ordering could be realized by letting the participants rearrange the location of the sticky notes where the highest significance should be placed on the top of the sheet.

3. Report - Workshop #2 and #3

Date workshop 2: 23/05/2023
Location workshop 2: Den Hague
Date workshop 3:: 22/06/2023 **Location workshop 3**: Amsterdam

The logbook presentation of the latest conducted workshop is presented combined in this section. Due to the fact that the workshop program was held exactly the same for the two worhops there is no need for separate presentation.

Participating disciplines

In total two (2) and (6) participated to the second and third workshop sessions respectively. The represented disciplines by these participants are presented in Table A3

Table A3: Participant overview of workshop session #2 and #3. The term 'Ns' refers to not specified, as deemed required to minimize the chance of participant reidentification

Profession	**Discipline**	**Number of participants**
	Workshop session #2	
Landscape designer	Ns	1
Urban designer	Ns	1
	Workshop session #3	
Project employee	Natural playgrounds	1
Project employee	Urban green	2
Project employee	Urban studies	1
Project leader	Urban green	1
Trainee	Urban green	1

Workshop Program

The workshop program for both the second and third workshop sessions remained consistent and is posited as the culminating phase of development within this research endeavour. While a detailed description of this program is provided in the main report, it's important to highlight a subtle differentiation concerning the technologies under consideration. During the second workshop session, all five integrated technologies were thoroughly deliberated upon. Due to the relatively compact size of the group, the brainstorming activity concluded expeditiously, thereby affording more time for the exploration of other innovations. Notably, the allotted timeframe for this workshop was 90 minutes, affording the opportunity for its expansion.

The third workshop, similarly, encompassed discussions on multiple innovations. Specifically, the "Boomveer," "Permeable Substrate of Koers," and "ZOAK Tiles" were deliberated upon. Given that all technologies had been previously covered in earlier workshop sessions, participants were assigned a technology at random to ensure equitable engagement.

1. **Informed Consent**
   Participants are briefed on the research objectives and the utilization of their generated

data within the study. The data generation format and processing methodology are clearly communicated. Additionally, participants are explicitly instructed to avoid disclosing personally identifiable information in adherence to the approved ethical guidelines (HREC). Approximately 5 minutes should be allocated to this step.

2. **Workshop Introduction & Context**
The workshop initiation encompasses a comprehensive contextual introduction. The extent of this introduction is tailored to workshop constraints, considering both time availability and participant familiarity with the subject matter. The primary aim is to ensure participants possess an adequate understanding of the focal subject. Thus, an exposition on the UHI effect problem ensues, encompassing its origins and consequential impacts. This is followed by the elucidation of the research domain, which includes elaboration on TGV site. Both the conventional and new Heat Square designs are expounded upon, highlighting ongoing principal research endeavours. Concerning the new Heat Square design, an overview of the study's incorporated innovations is provided, albeit without intricate details at this stage. Subsequently, the crux issue of interdisciplinary integration deficits within UHI mitigation is introduced, exemplifying potential contributing disciplines. This introduction draws upon slides [1] to [5], as outlined in the designated material list in Appendix A of this report. Approximately 10 to 15 minutes should be allocated to this step.

3. **Data Generation Explanation**
Participants will receive detailed instructions on data generation. The following query "What information is required about an innovation that aims to mitigate the UHI effect to implement this within the urban environment" is used for this data generation. Another framing involves prompting participants to contemplate inquiries pertinent to the assessment or deployment of such technologies. The participants are informed that they should write these requisites and queries on a sticky note. This format is specifically favoured as it allows for participants to articulate in a way they prefer (phrase, sketches, sentences, etc.). Simultaneously they are informed that they can place that sticky note in one of six topic clusters. However, it is crucial to emphasize that the objective of this exercise is not data allocation, but rather that these topic clusters are introduced to cultivate multidimensional thinking and stimulate a wider data generation. The facilitator will illustrate the data generation process by offering an exemplar corresponding to each topic cluster. Slides [11] till [13] of the presented material (Appendix A) should be utilized and approximately 10 minutes should be allocated to this step.

4. **Introduction Innovation**
One of the five innovations incorporated in this research is now fully introduced to the participants. This introduction will is based on the hypotheses displayed in Section 5.1.2. The core objective of this step is to give the participants a general idea of the innovation that stimulates them to think about which information is additionally needed for the assessment and/or implementation of this innovation. The specific technology slide in Appendix A (slides [6] up to [10]) should be used for this step. Approximately 5 to 10 minutes should be allocated to this step.

5. **Brainstorm Activity**
The participants are now instructed that they may embark on data generation, as outlined in step [3], focusing specifically on the innovation introduced in the preceding phase. They are informed of the option to undertake this task individually or collaboratively with other participants. Additionally, they are briefed on the possibility of expanding

upon existing data entries should they encounter difficulties generating novel data. To elucidate this notion, the example of "Costs" may be further dissected into subcategories like "Installation costs," "Energy Costs," "Maintenance costs," and so forth. To facilitate a productive brainstorming session, a minimum duration of 20 minutes is allotted for this activity. However, this time frame can be extended, contingent upon session time constraints. For comprehensive participant guidance, an overarching slide outlining the activity's objective, the innovation's details, and visualization of the potential outcome of this activity is provided (slides [11] Appendix A). The facilitator will oversee and direct this activity, remaining available for participant inquiries.

6. **Iteration Step [4] & [5]**
   If time constraints permit, workshop steps [4] and [5] can be successively employed for the remaining innovations. For each subsequent innovation, the brainstorming session can be condensed to a minimum of 10 minutes, given that numerous generated data possess a broader scope applicable to multiple innovations concurrently. Participants are directed to employ distinct coloured sticky notes for each newly introduced innovation, facilitating data-innovation correlation.

7. **Closing Statement, Feedback & Discipline Identification**
   Upon meeting time constraints or participants expressing an inability to further generate data, the session is concluded. The closure commences with an appreciative statement, acknowledging participants and reiterating the importance of their informed consent. Subsequently, participants are requested, if agreeable, to offer a broad depiction of their respective disciplines. This description should strike a balance between specificity to allocate the pertinent disciplines and generality to preclude personal identification. As a precautionary measure, the facilitator will review each discipline description before collection. The session draws to a close with an open discussion asking for constructive feedback to enhance future iterations of the workshop.

Workshop Materials

As the final stage of development of the workshop is presented here, a required list of materials is given. It is advised to print the material in A3 format as room is required to place the sticky notes.

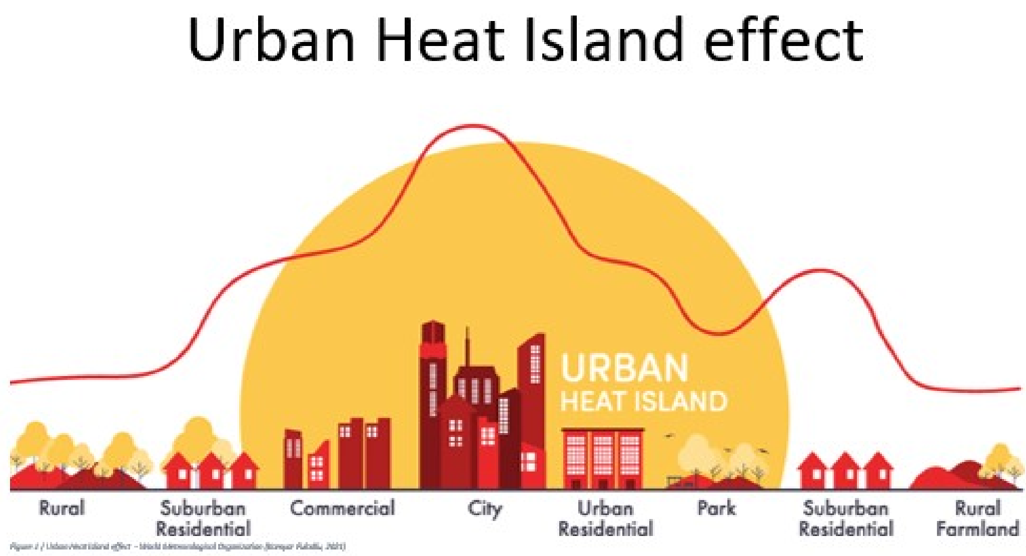
- Slide deck as presented in Figure 7c
- Sticky notes; approximately 150 per workshop session. If in online format this could be done in Mirosoftware.
- Stationary
- Stopwatch
- If performed in person: a table big enough for the printed materials to be presented.

3.1. Evaluation facilitator

Both workshops were characterized by seamless and efficient execution. Notably, the workshops transpired without encountering any challenges, thereby yielding a substantial number of outcomes. Consequently, no specific points of concern or notable issues emerged from the workshop sessions.

3.2. Received feedback

The overarching feedback from both workshop sessions highlighted the necessity for such sessions in promoting discipline linkage, facilitating efficient knowledge transfer, and effectively identifying persistent knowledge gaps. Given that these outcomes align closely with the overarching objectives of this research, it can be asserted that the development and execution of the workshops have successfully fulfilled their intended purpose. As a result, no further areas for improvement in the workshop design are warranted.



(a) Slide [1]

(b) Slide [2]

(a) Slide [3]

(b) Slide [4]

Figure 2: Overview of slide deck used used during workshop sessions

(a) Slide [5]

(b) Slide [6]

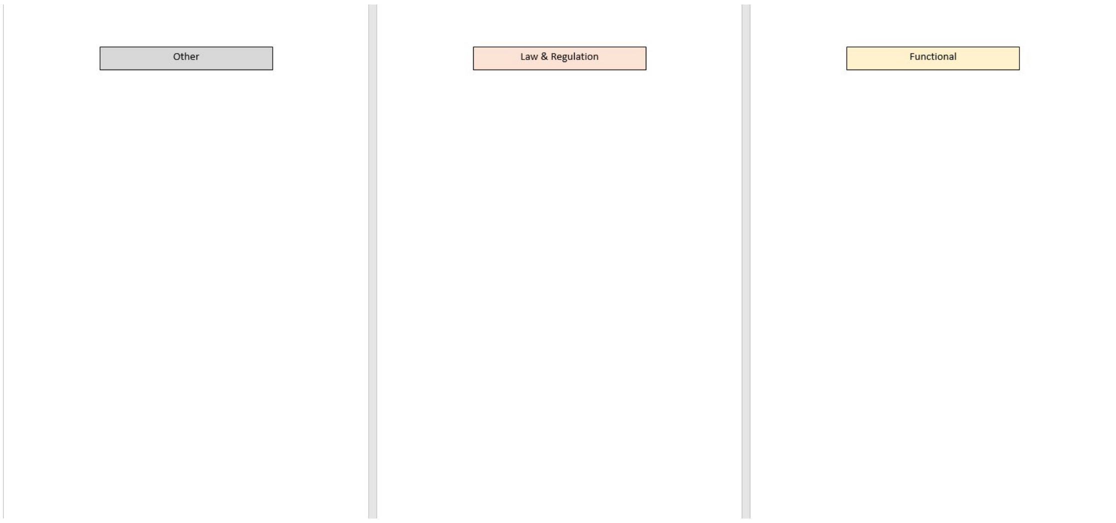
(a) Slide [7]

(b) Slide [8]

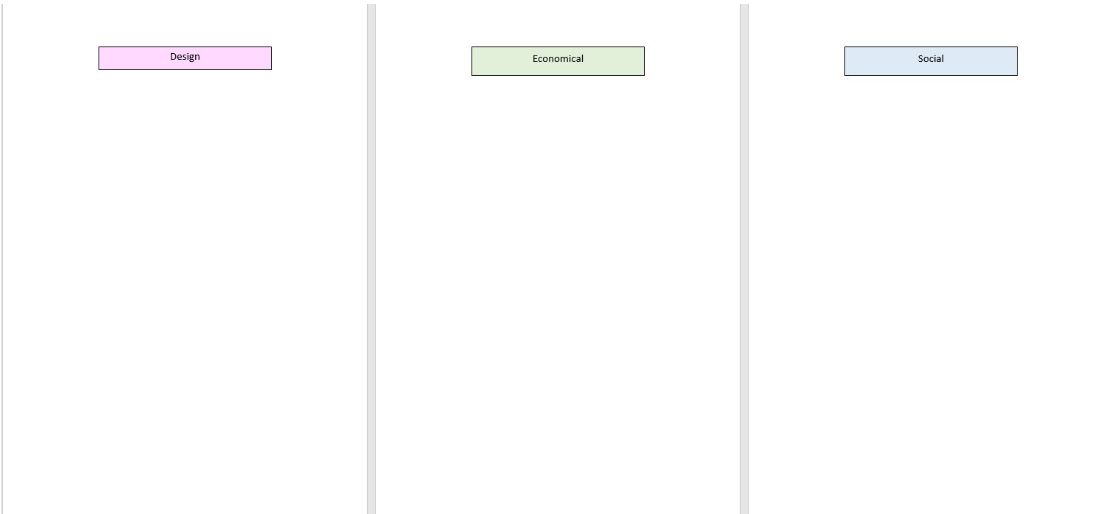
(a) Slide [9]

(b) Slide [10]

Figure 6: Slide [11]



(a) Slide [12]



(b) Slide [13]

(c) Overview of slide deck used used during workshop sessions

Appendix B. Typology

1. Typlogy Results - Literature

Table B1: Overview of raw typology data gained by literature-base approach

Begin of Table

Raw typology data entry	**Reference**
Reliability	Puig et al. [2021]; Haselip et al. [2019]
Functional uncertainty	Puig et al. [2021]
Energy Efficiency	Puig et al. [2021]
Scale	Yamamoto [2006]; Lucertini et al. [2022]
Period	Yamamoto [2006]
Degree of effect	Yamamoto [2006]
Energy savings	Qi et al. [2022]; Lucertini et al. [2022]
Water storage capacity	Lucertini et al. [2022]
Urban cooling	Qi et al. [2022]
Outdoor thermal comfort index	Qi et al. [2022, 2020]
Heat reduction	Qi et al. [2022]
Air temperature	Qi et al. [2020, 2022]
Land surface temperature	Qi et al. [2020, 2022]; Lucertini et al. [2022]
PM 2.5	Qi et al. [2020]
Nocturnal air temperature	de Groot-Reichwein et al. [2018]
UHI reduction	Lucertini et al. [2022]
Quality	Reliability
Haselip et al. [2019]; Puig et al. [2021]	
Technological quality	Haselip et al. [2019]
Vulnerability	Boland et al. [2021]; Qi et al. [2022]; Lucertini et al. [2022]
Vulnerability to removal	O'Malley et al. [2015]
Environmental sensitivity	Qi et al. [2022]
Density	Boland et al. [2021]; Qi et al. [2020]
Energy demand	Puig et al. [2021]
Water demand	Puig et al. [2021]; Lucertini et al. [2022]
Space	Puig et al. [2021]; Qi et al. [2022]
Dimensions	Qi et al. [2020]
Impact on environment	Haselip et al. [2019]; O'Malley et al. [2015]; Qi et al. [2022]
Synergy potential	Puig et al. [2021]; Qi et al. [2022]
Trade-off effect	Puig et al. [2021]
Heat waste	Puig et al. [2021]
Soil drought	Lucertini et al. [2022]

Continuation of Table B1	
Raw typology data entry	Reference
Location of deployment	Qi et al. [2022, 2020]
Density	Qi et al. [2020]; Boland et al. [2021]
Dimensions	Qi et al. [2020, 2022]
Built area ratio	Lucertini et al. [2022]; Qi et al. [2022, 2020]
Tree canopy area	Qi et al. [2022]
Root depth	Qi et al. [2022]
Vegetation height	Qi et al. [2022]
Green surface area	Lucertini et al. [2022]
Normalized vegetation index	Lucertini et al. [2022]
Normalized built up index	Lucertini et al. [2022]
Aesthetics	Building type
Qi et al. [2022]	
Shape	Qi et al. [2022]
Color	Qi et al. [2020, 2022]
Material	Surface characteristics
Qi et al. [2022]	
Vegetation species	Qi et al. [2020, 2022]
Material	Qi et al. [2020, 2022]
Melting temperature	Qi et al. [2022]
Permeability	Qi et al. [2022]; Lucertini et al. [2022]
Costs of capital	Haselip et al. [2019]; Puig et al. [2021]
Investment costs	Haselip et al. [2019]
Affordability	Puig et al. [2021]
Implementation costs	Lucertini et al. [2022]; Qi et al. [2020, 2022]
Rate of return	Haselip et al. [2019]
Payback time	Puig et al. [2021]
Economic productivity	Qi et al. [2022, 2020]
Running costs	Puig et al. [2021]
Energy costs	Haselip et al. [2019]; Qi et al. [2022, 2020]
Operating costs	Puig et al. [2021]
Water costs	Qi et al. [2020]
Maintenance costs	Lucertini et al. [2022]
Management costs	Lucertini et al. [2022]
Likelihood of investment	Boland et al. [2021]; Lucertini et al. [2022]
Market conditions	Haselip et al. [2019]
Distribution network	Haselip et al. [2019]
Financial incentives	Puig et al. [2021]
Investment horizon	Puig et al. [2021]
Green marketing	Haselip et al. [2019]
Conflicts of economic interest	Haselip et al. [2019]
Authority over urban planning	Boland et al. [2021]
Legal framework	Haselip et al. [2019]
Actor involvement	Haselip et al. [2019]

Continuation of Table B1	
Raw typology data entry	Reference
Property ownership	Puig et al. [2021]
Bureaucracy	Puig et al. [2021]
Institutional arrangement/siloed thinking	Puig et al. [2021]
Legal considerations	Qi et al. [2022]
Administrative considerations	Qi et al. [2022]
Legal feasibility	Lucertini et al. [2022]
Procedural time	Lucertini et al. [2022]
Subsidies potential	Haselip et al. [2019]
Conflicts of interest	Haselip et al. [2019]; Puig et al. [2021]
Management capacity	Haselip et al. [2019]; Puig et al. [2021]
Available resources	Puig et al. [2021]
Policy support	Puig et al. [2021]
Political commitment	Puig et al. [2021]
Monitoring capacity	Puig et al. [2021]
Political acceptance	Lucertini et al. [2022]
Growth of city	Boland et al. [2021]
Available space	Boland et al. [2021]
Public acceptance	Boland et al. [2021]; Haselip et al. [2019]; Puig et al. [2021]; O'Malley et al. [2015]; Lucertini et al. [2022]
Population growth	Boland et al. [2021]
Consumer preference	Haselip et al. [2019]
Public awareness	Haselip et al. [2019]; Puig et al. [2021]
Ownership	Puig et al. [2021]
Resistance to change	Puig et al. [2021]
Public knowledge	Puig et al. [2021]
Public health	Qi et al. [2022]
Social sensitivity	Qi et al. [2022]
Place of deployment	Qi et al. [2022]
Mortality and morbidity	Qi et al. [2020, 2022]
Job creation	Lucertini et al. [2022]
End of Table	

2. Typology Results - Workshops

Owing to the substantial volume of these outcomes and the associated definitions, this dataset is provided as a separate attachment to this report, accessible in the document titled "Processed Typology Results from Workshop-Based Approach." It is important to highlight that engaging with this dataset is advised only in conjunction with a comprehensive understanding of its intended purpose, the underlying methodologies, and the intricacies of the data processing procedure.

3. Total Typology Results

The complete merged dataset is furnished as a distinct attachment to this report, conveniently available in the document labelled "Full Typology Dataset." As previously mentioned, interacting with this dataset is recommended only when accompanied by a thorough grasp of its intended purpose, the underlying methodologies, and the intricacies of the data processing procedure.

Appendix C. Typology Questionnaires

The complete tailored questionnaire for the Boomveer innovation is furnished as a distinct attachment to this report, conveniently available in the document labelled "Questionnaire Tailored to Boomveer".

Appendix D. Identification & Justification process knowledge gaps

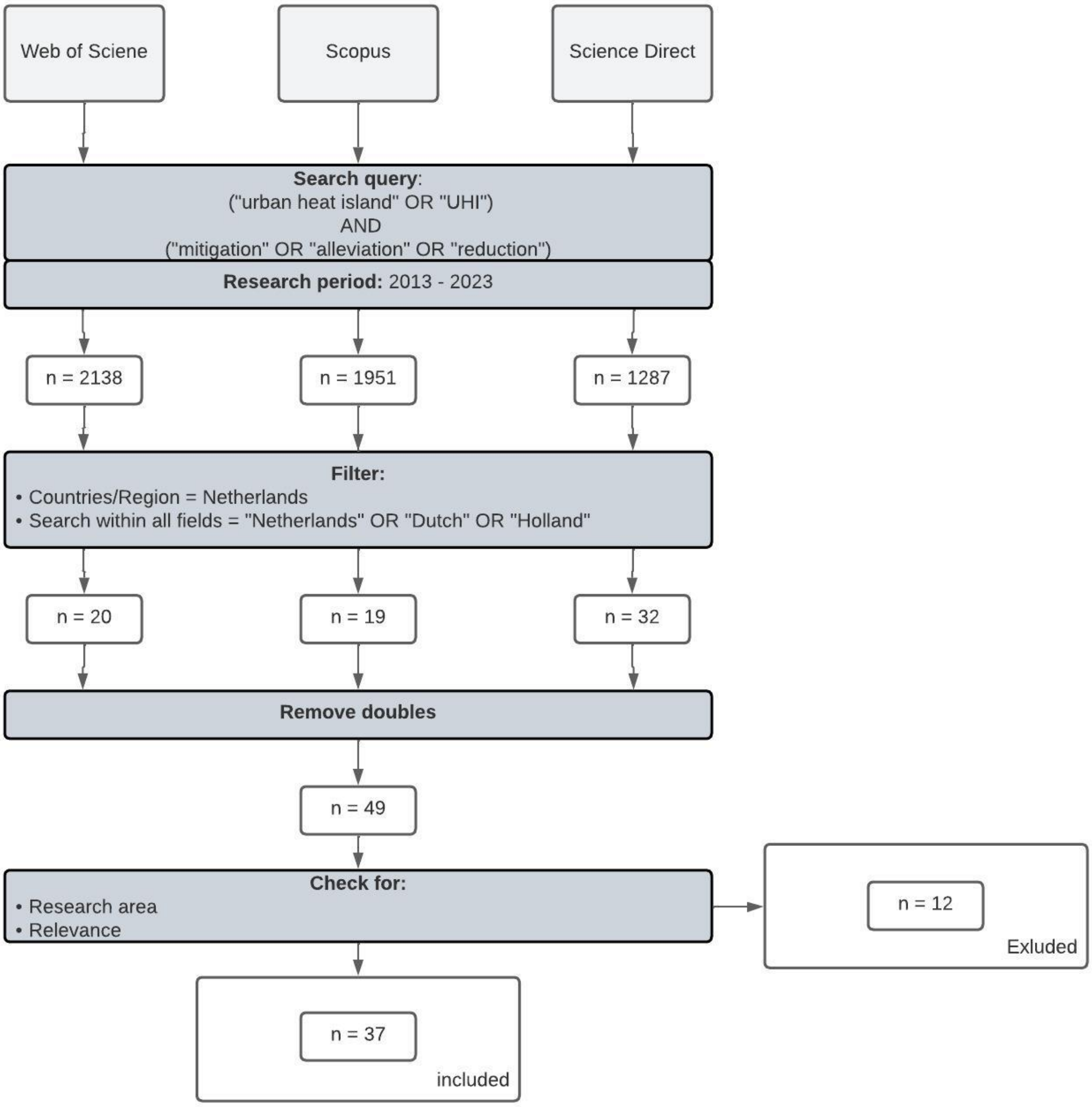
This appendix presents the full description of the identification & justification process of the knowledge gaps central to this Research.

1. Knowledge gap

Aside from the consensus concluding on the origins and effects of the UHI effect presented and substantiated by the literature mentioned above, there are notable dissimilarities within research trends as results highly suggest the presence of prevailing knowledge gaps within the existing literature. This potential incompleteness will be justified by comprehensive studies investigating research trends within the domain of UHI and through the results of a systematic literature search. Regarding the latter, a broad search query has been set up within three widely acknowledged search engines: Web of Science, Scopus and Science Direct, as depicted in Figure C1. The keywords presented in Table C0 are used for this query with a limitation to studies only performed in the last decade to ensure scientific relevance. The combined results of this effort (n = 5376) are assessed following the inclusion and exclusion criteria presented in Table C0. Ultimately, the findings resulting from this approach are categorized and delivered within the Section 1.1 till Section 1.3.

Table C0: Overview of utilized keywords and inclusion criteria for the literature search query (own table).

Key Words	*'urban heat island'* OR *'UHI'* AND *'mitigation'* OR *'alleviation'* OR *'reduction'*
Inclusion criteria	Research needs to be conducted in Netherlands OR Research includes case study conducted in the Netherlands OR Research presents a comprehensive overview applicable to the Netherlands



centring

Figure C1: Literature search process performed in Web of Science, Scopus and Science Direct. Performed on 03/02/2023 utilizing University license

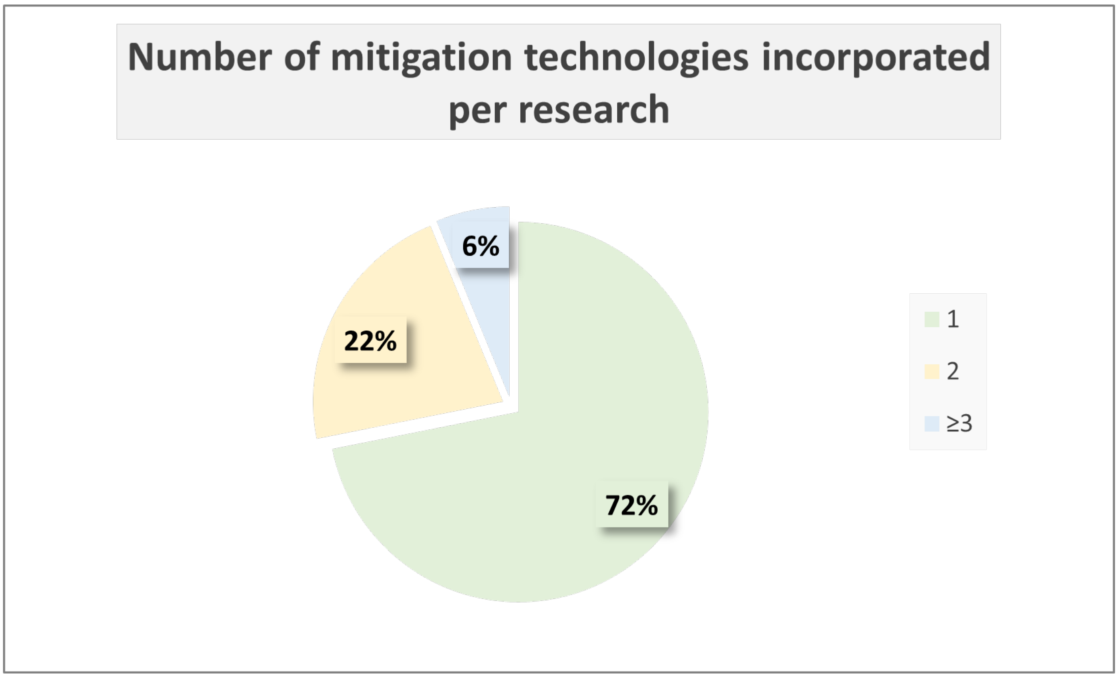
1.1. Geography

A systematic literature review by Aleksandrowicz et al. [2017] identified a geographical dissimilarity in initiating research into this topic. Potentially explicable to a combination of climatological differences within exposure to thermal stresses, the significance of the effects and ultimately the necessity to adapt, Research is predominantly concentrated in East Asia (China, Japan, Hong Kong, Taiwan, South Korea) and North America (United States of America). Research performed by, among others, Mohammad Harmay and Choi [2022] and Geng et al. [2023] concluded that climatological variations are positively correlated with the UHI phenomenon intensity and therefore proves to be inapplicable within other climate zones. This, combined with a substantial lack of performed Research into UHI effects in Dutch urban environments, contributes to the geographical lack of knowledge on this topic for the Netherlands. Despite research activities focusing on UHI effects in Dutch cities gaining notable momentum after the heat wave occurrence of 2003, which was responsible for a heat-related mortality rate between 1400 and 2200 people [Garssen et al., 2005], it remains relatively insignificant compared to its international counterpart [Echevarría Icaza et al., 2016].

The completed literature search also validates the scarcity of performed Research explicitly focusing on the UHI phenomenon in Dutch urban settings. All collected studies (n = 5376) were filtered based on Country/Region, including only those conducted in the region of interest or by someone originating from the area of interest. Furthermore, a specific search on the keywords 'Netherlands', 'Dutch' and 'Holland' within all fields of the performed studies is executed to narrow the scope. After removing double-collected studies, the results are fully read and reviewed based on the predefined criteria presented in Table C0. Ultimately, this yielded 37 included studies, which are either entirely conducted within the Netherlands (n=20), incorporate case studies within the Netherlands (n=8) or give a more generalized overview of trends which are assumed to be applicable to construct the scientific embodiment of this Research (n=9). Although studies performed in similar climatological areas to that of the Netherlands could potentially elevate the number of incorporable studies [Weather and Data, 2023], these do not include countries identified with large numbers of UHI mitigation-related research, hence supporting those arguments already presented by Echevarría Icaza et al. [2016] and Aleksandrowicz et al. [2017] indicating this geographical knowledge gap.

1.2. Assessed mitigation technologies

Efforts studying mitigation technologies to relieve urban areas from negative UHI-related effects tend to incline towards a limited set of approaches. Comprehensive Research concluding on trends within UHI mitigation technology research performed by Deilami et al. [2018], Santamouris and Kolokotsa [2016], Aleksandrowicz et al. [2017], Rehan [2016] and mention giguere2009 consent that mitigation efforts predominantly utilize either the reduction of solar radiation adsorption in the urban fabric, the enhancement of airflow through the urbanized area, or use active cooling pathways via evaporation and evapotranspiration. Furthermore, they conclude that the most investigated mitigation technology to achieve one or more of these pathways is, by far, the implementation of vegetation. This broad term incorporates city parks, street-level vegetation, green roofs, and even innovative urban greenery approaches such as vegetated facades. However, these studies do not include innovative design strategies such as the 'breeze' mechanism (Table 3.1). Furthermore, other mitigation technologies that focus on the urban envelope characteristics (sky view factor, albedo, orientation, build density), the incorporation of water bodies, the modification of the thermal properties of building and construction materials used in urban areas, and the environmental management (anthropogenic



centring

Figure C2: Pie chart visualizing the number of mitigation technologies incorporated per Research of all incorporated literature (own figure).

heat reduction) are not only less accounted for; they hardly include innovative pathways such as cool pavement concepts. This inclination towards vegetation-orientated solutions is also identified through analysis of the included studies showing that more than half (n = 19) utilize a form of vegetation, seven studies focus on the urban envelope, less than a third (n = 10) on the effect of water bodies, and ultimately eight on modification of thermal properties. This unbalanced form of Research directs developments unilaterally, hence discriminating its true potential despite Santamouris and Kolokotsa [2016] concluding on the considerable increase of mitigation potential when more technologies are combined within a synergetic design.

Another trend identified through this analysis is that most of the included Research focuses on one specific mitigation technology rather than the simultaneous effect of numerous as depicted in Figure C2. This, too, is identified within Research performed by Aleksandrowicz et al. [2017] and Santamouris and Kolokotsa [2016], which concludes that 60% out of 411 articles and 90% out of 220 included articles purely focus on one specific mitigation technology, respectively. Hence, studies expanding its scope to multiple mitigation technologies and their simultaneous effect within an inclusive design are currently lacking.

1.3. Interdisciplinary linkage

Last and most central to the core of this Research is the prevailing knowledge gap between the scientific knowledge on UHI mitigation and the implementation thereof. Argued by, amongst others Alcoforado et al. [2009], Aleksandrowicz et al. [2017] and Oliveira et al. [2020], the challenge originates from the complexity of the topic in combination with the inherent difficulties of transposing acquired knowledge interdisciplinary to other non-scientific stakeholders comprehensively. They conclude that these challenges lead to incorrect assessment of results and ultimately restrain them from being implemented. Despite significant scientific contributions in researching this theme, the discussion of a new framework of presenting UHI mitigation knowledge for interdisciplinary usage is still in an early stage. It remains underdeveloped [Lee and Kim, 2022]. This is attributable to research results presented by Aleksandrowicz et al. [2017]; Bosch et al. [2013]; Rizwan et al. [2008]; Döpp et al. [2011]; Lee and Kim [2022] and Akbari et al. [2016] who similarly give UHI mitigation knowledge as a summarized overview textually elaborating on the cooling mechanisms as well as offering literature references concluding on their qualitative effects. However, these assessments fail to interlink the practical implementation of these technologies due to insufficient knowledge of what planners need for implementation within the urban design process of these results. This is also identified by [Eliasson, 2000] and concluded to be coupled to a set of four major contributors being: (1) the planners feel uncertain about their (technological) knowledge and lack arguments to debate for employment, (2) overall lack of knowledge on how, where and when these technologies can be implemented, (3) communication problems between scientific knowledge and their implementation leading to lack of understanding of results, and (4) lack of easily accessible mitigation techniques and their supporting literature. Despite these dilemmas being identified, current literature fails to satisfy these needs. Additionally, attempts to provide urban planners and policymakers with such a comprehensive applicable tool, as done by [Wang et al., 2021], concludes that these remain impractical due to their required need for expertise on the software interface and the underlying thermodynamic processes of the tool. To synthesize, the form of UHI mitigation knowledge presentation needs improvement due to its current state failing to connect different fields of involved expertise, lacks direct applicability for urban implementation processes, and does not efficiently transfer acquired knowledge. By Corburn [2009], a co-production framework, based on the involvement of both technical as well as urban design expertise, is assumed to ultimately close this gap and contribute to a more scientifically legitimate approach needed to realise 'cool cities' [1].

[1] The term "cool city" here is referred to as "sustainable urban solutions for the city of tomorrow that depends on the application of the principles of urban heat management. It is the key factor to diminishing urban heat release, creating solutions for future climate change by reducing the volume of global emissions, and creating smart growth and cool community scenarios" [Arrau and Peña, 2010]

TU Delft