

## Shape of Water and Daily Life

: Measuring and Leveraging the Climate-Adaptive Potential  
of Seoul's Waterfronts

Yoon Ji Kim  
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**Title** Shape of Water and Daily Life  
: Measuring and Leveraging the Climate-Adaptive Potential  
of Seoul's Waterfronts

**Graduation Lab** City of the Future

**Author** Yoon Ji Kim

**Student Number** 6170226

**First Supervisor** Claudiu Forgaci (Urbanism)

**Second Supervisor** Mark Voorendt (Civil Engineering)

## Abstract

Seoul's waterfronts with distinct enclosed profiles provide refuge from heatwaves and mitigate damage caused by flash floods, two hazards that have recently worsened due to climate change. The aim of this study is to investigate how the morphology of these waterfronts influences climate-adaptive performances, and through this, the qualities of daily life. To address this objective, this study proposes a framework that integrates climate adaptivity analysis with data-driven design. Its analytical implementation is demonstrated on 20 waterfronts in Seoul through 7 spatial variables that assess their ability to provide refuge from heatwaves and mitigate damages from flash floods. Four types of waterfronts were identified through qualitative classification of the results: Flood-safe & high thermal performance, Flood-safe & low thermal performance, Vulnerable pedestrian network if flooded, and Likely to flood & low-moderate thermal performance. The framework's ability to generate design variations is further tested on three waterfronts, guided by principles of daily life walkability and feasibility. Results demonstrate that integration of morphological analysis with data-driven design can produce waterfront interventions that simultaneously strengthen climate adaptivity during extreme summer events and improve daily life walkability under moderate climate.

**Keywords :** *Climate-adaptive Urban Design, Environmental urban morphology, Waterfront Urbanism, Heat Mitigation, Flood Mitigation, Everyday Urban Life*

# Content

Preface	2
<b>Part 1 Introduction</b>	<b>4</b>
1.1 Problem statement	6
1.2 Objectives	8
1.3 Research questions	10
1.4 Relevance	12
1.5 Scope	16
<b>Part 2 Approach</b>	<b>18</b>
2.1 Conceptual framework	20
2.2 Theoretical framework	21
2.3 Scalar framework	26
2.4 Methodology	28
2.4.1 Sub-question 1: Waterfront and area of influence definition	30
2.4.2 Sub-question 2: Evaluation and classification of waterfronts	34
2.4.3 Sub-question 2a: Calculation of flood buffer capacity	36
2.4.4 Sub-question 2b: Calculation of flooded mobility robustness	40
2.4.5 Sub-question 2c: Calculation of thermal relief	42
2.4.6 Sub-question 2d: Calculation of thermal refuge accessibility	44
2.4.7 Sub-question 3: Design principles	46
2.4.8 Sub-question 4: Site-specific design interventions	47
<b>Part 3 Results</b>	<b>48</b>
3.1 Waterfront & areas of influence	
3.1.1 Waterfront definition	50
3.1.2 Areas of influence	54
3.2 Evaluation of waterfronts	
3.2.1 Performances against heatwaves	56
3.2.2 Performances against flash floods	58
3.2.3 Combined analysis per waterway	60

3.3 Waterfront classification	62
3.4 Design principles	66
3.5 Design Process	67
3.5.1 Design step 1: Identification of effective design locations	68
3.5.2 Design step 2: Selection of spatial elements	69
3.5.3 Design step 3: Spatialization of elements and creation of variations	70
3.5.4 Design step 4: Evaluation and selection of optimal design	72
3.6 Implementation of developed design process in real sites	74
3.6.1 Implementation of developed design process in Jungrang-3	76
3.6.2 Implementation of developed design process in Hongje-3	106
3.6.3 Implementation of developed design process in Hangang-1S	124
<b>Part 4 Conclusion &amp; Discussion</b>	<b>152</b>
4.1 Conclusion	154
4.2 Discussion	
4.2.1 Validity of variables used in analysis	158
4.2.2 Framework - limits and potentials	162
4.2.3 Applicability of framework in reality	165
4.3 Reflection	166
<b>References</b>	<b>168</b>
<b>List of Figures</b>	<b>173</b>
<b>List of Tables</b>	<b>179</b>
<b>Appendices</b>	<b>180</b>
A : Coefficients used to calculate variables	182
B : Climate-adaptivity results of 20 waterfronts	184
C : Classification based on original variables	186
D : Process of deriving design elements from variables	188
E : Design iterations	190
F : Design case studies	196

## Preface

Coming from one of the few countries where baseball is popular, sabermetrics –statistical analysis of player and team performance to predict future outcomes– is a familiar concept to me. As I followed the games, I was fascinated by its intricate system where each index showed one section of reality – a complex reality whose truth can only be glimpsed by combining multiple different indices representing the innumerable factors that influence the game individually and collectively. My thesis began with looking at cities with a similar perspective; space is undoubtedly a key player –perhaps as important as the fourth batter– but only one of many. What we need to do as designers and urbanists is to fully embrace this limit by refactoring the game with space as its anchor point. To do so, we must start with specific, real-life moments that are directly linked to certain spaces– for example, extreme summers and waterfronts.

This report was written for MSc Urbanism thesis at Delft University of Technology. It consists of four parts: introduction, approach, results, and conclusion. <Part 1: Introduction> serves to clarify the objectives, scope and expected outcome of the project. In it are also explained why such a project is necessary and how it can be used in the real world. <Part 2: Approach> clarifies the theoretical, methodological and scalar frameworks that structures the study. Following <Part 3: Results> presents the outcomes produced, and their implications and limitations are addressed in <Part 4: Conclusions and Discussions>.

Special thanks to my two supervisors: Claudiu and Mark who always guided me to steer away from pitfalls and not lose sight of the finish line. It was through their counsel that I was able to finish this study with satisfaction. Looking back at the time spent on this thesis will always bring back memories of joyful conversations with Yaying Hao, immense support from Kate Schuitemaker, and a timely visit from a childhood friend Myeongje Kim.

YoonJi Kim  
Delft  
02 June 2026

Images without explicit reference were made by author.

For sources of GIS layers used to create images, see List of Figures



## **Part 1**

### **Introduction**

1.1 Problem statement	6
1.2 Objectives	8
1.3 Research questions	10
1.4 Relevance	12
1.5 Scope	16



## 1.1 Problem statement

Seoul's waterfronts that were originally constructed as carriers of water alone later transformed into staple outdoor public spaces in the daily life of the city's people. Functions such as recreation, mobility, and even place-making have been added to them, as the famous restored urban stream Cheonggyecheon (Figure 1) has well proven. On the other hand, the elongated summers worsened by climate change introduced another dimension to the daily life happening in and around the waterfronts – performances against flash floods and heatwaves (Figure 2).

However, urbanists do not yet have adequate knowledge to address these rising challenges through open space design. Most existing morphological studies on cooling effect (Schmidt, 2024) and flood mitigation (Mabrouk et al., 2024) focus on the built fabric. Consequently, we do not have the means to determine if a certain waterfront design will improve performances related to heat and flood mitigation. Moreover, while the idea of utilizing urban water infrastructures to address both heat and flood issues with a more holistic approach has been proposed (Richards & Edwards, 2018) and spatial interventions have been assessed through such comprehensive framework (Majidi et al., 2019) it remains unclear how daily life will be affected by these performance-centered strategies.

Regardless of the knowledge gaps between open space and daily life under extreme climatic events, Seoul City has been diligently planning and rebuilding the waterfronts. During the last five years, several waterfront projects have been launched (Seoul Metropolitan Government, 2023b, 2025) in accordance with to 'Great Hangang Project' (Seoul Metropolitan Government, 2023a) and 'Waterside City' (Water Circulation Safety Bureau, 2025) visions that promise improved walkability and landmark aesthetics. However, climate change is not listed in their agenda, nor are they conscious of the likelihood of altering the basic sensory and safety conditions of the waterfronts.



Figure 1 : Restored Cheonggyecheon – quintessential waterfront of Seoul (The Seoul Institute, 2014)

*Waterfronts with different forms and urban context*



? ?

*Flash floods*

*Heatwaves*



Figure 2 : Different morphologies of Seoul's waterfronts(1-4) and affected daily life during extreme summers (5-6)

- 1-4 The Seoul Institute (2020)
- 5 Chosun Media (2025)
- 6 Kukminilbo (2018)

## **1.2 Objectives**

The main objective of this study is to develop a framework that integrates analysis with design to help designers and stakeholders implement optimal climate adaptive spatial interventions that enhance the quality of daily life occurring in and around Seoul's waterfronts (Figure 3).

### **Analysis**

The purpose of the analytical section is to a) to diagnose the status quo of waterfronts and b) to qualitatively classify them based on the performances against extreme floods and heatwaves. Results from this section provide foundation for the development of design principles. They also contribute to identification of effective locations to implement climate-adaptive interventions and provision of spatial elements that can be leveraged to improve certain performances against heatwaves and flash floods.

### **Design**

In terms of design, the framework consists of a system to provide variations of site-specific design. It also proposes a method to facilitate stakeholder involvement in deciding the most optimal design. In the former part, design principles guide the direction of how to identify effective locations and leverage spatial elements for a given site. As a result, several possible options of site-specific spatial interventions are produced. In the latter part, stakeholder participation is realized through evaluation of these products which leads to the selection of final design.

Framework

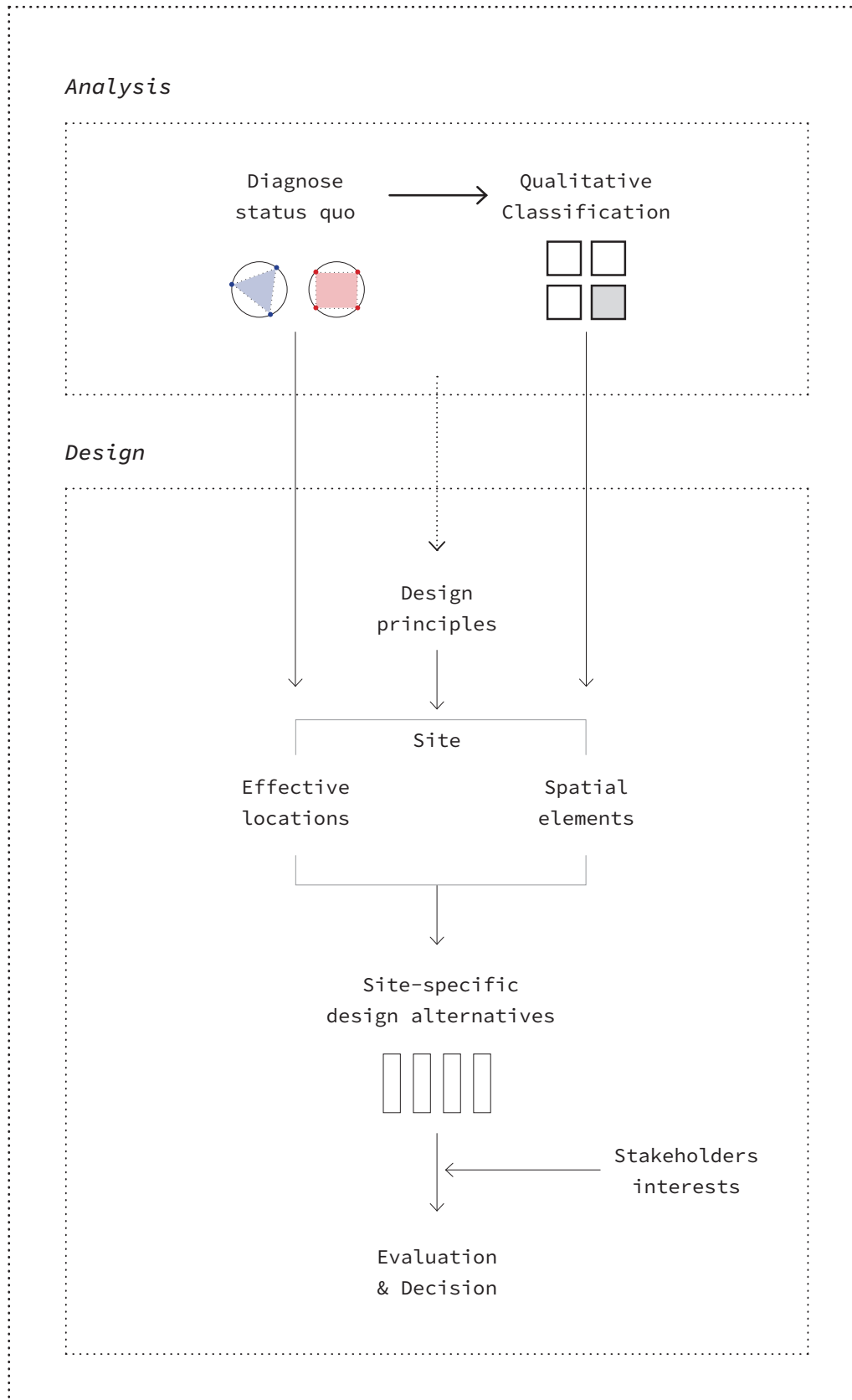


Figure 3 : Structure of proposed framework

### 1.3 Research questions

The main question addresses the issue of measuring and leveraging the impacts of waterfronts' spatial properties. To answer it, a quantified framework that can compare different waterfronts based on their spatial characteristics and generate climate adaptive design strategies must be developed.

.....

*How can spatial impacts of Seoul's waterfronts on climate adaptivity be measured and leveraged to enhance trajectories of daily life?*

.....

The first two sub-questions refer to the beginning and the end of the analytical section. The first step of the analysis segments waterfronts and defines their areas of influence. The output would be the evaluation and classification of them based on their climate adaptive performances. To produce the desired output, spatial characteristics that contribute to climate adaptive capacities against each criterion are identified and measured as specified in sub-questions 2a to 2d.

.....

#### Sub-question 1

*What is the spatial extent of a waterfront in Seoul, and the area of influence regarding heat waves and flash floods in the summer?*

#### Sub-question 2

*How can Seoul's waterfronts be evaluated and classified by spatial characteristics that affect daily life during extreme summers?*

.....

#### Sub-question 2a

*To what extent can waterfronts withhold floods during severe rainfalls?*

#### Sub-question 2b

*What is the extent of disruption on mobility networks when waterfronts become flooded?*

#### Sub-question 2c

*What is the extent of thermal relief provided by the waterfronts, compared to their surrounding urban area during heat waves?*

#### Sub-question 2d

*What is the level of accessibility to waterfronts that provide refuge from heat waves?*

The next two questions point to the design norms and processes necessary to successfully operationalize analysis results. The design principles addressed in the first question determine the direction and objective of design, which are then translated into design alternatives in the second question.

---

**Sub-question 3**

*Which design principles derive climate adaptive solutions that enhance quality of daily life trajectories from spatial analysis?*

**Sub-question 4**

*How can the proposed framework generate site-specific design interventions which stakeholders can evaluate and choose from?*

## 1.4 Relevance

### Scientific

This study adds on to the discourse surrounding open space design and daily life. However, unlike studies that approach daily life through a multi-dimensional concept of livability that includes various social, economic and morphological factors (Martino et al., 2021), this study deliberately limits its setting under severe climatic conditions in order to make the correlation between space and daily life more explicit. In other words, open spaces are viewed as containers of climatic phenomena that for a limited duration of time heavily influence human behavior (Figure 4 and 5). While repeated occurrence of extreme climatic phenomena in the long term will eventually render people to become proactive towards climate change, people's behavior as direct consequence of being exposed to heat waves or flash floods are undoubtedly reactive. This short-term condition allows climate adaptivity of urban space to function as a medium to understand the link between morphological factors and daily life evident and even quantifiable.

Correlation between climate adaptive open space design and daily life is investigated through operationalization of existing knowledge. While many studies have proven the impact of morphological factors on mitigating heat or flood (Mabrouk et al., 2024; Schmidt, 2024) how such formal features are related to daily life has yet been unexplored. This is mainly because the formal indicators are focused on built structures and are devoid of context, which may be sufficient for planning of large regions but not suitable for analyzing or generating designs of open spaces. To address this research gap, this study concentrates on the morphological features of open spaces and their surrounding networks. In summary, this study incorporates and operationalizes various theories and methods that originate from different fields - heat mitigation, flood damage assessment, and network theory - and synthesizes them in order to illustrate the formal implications of open spaces on daily life.

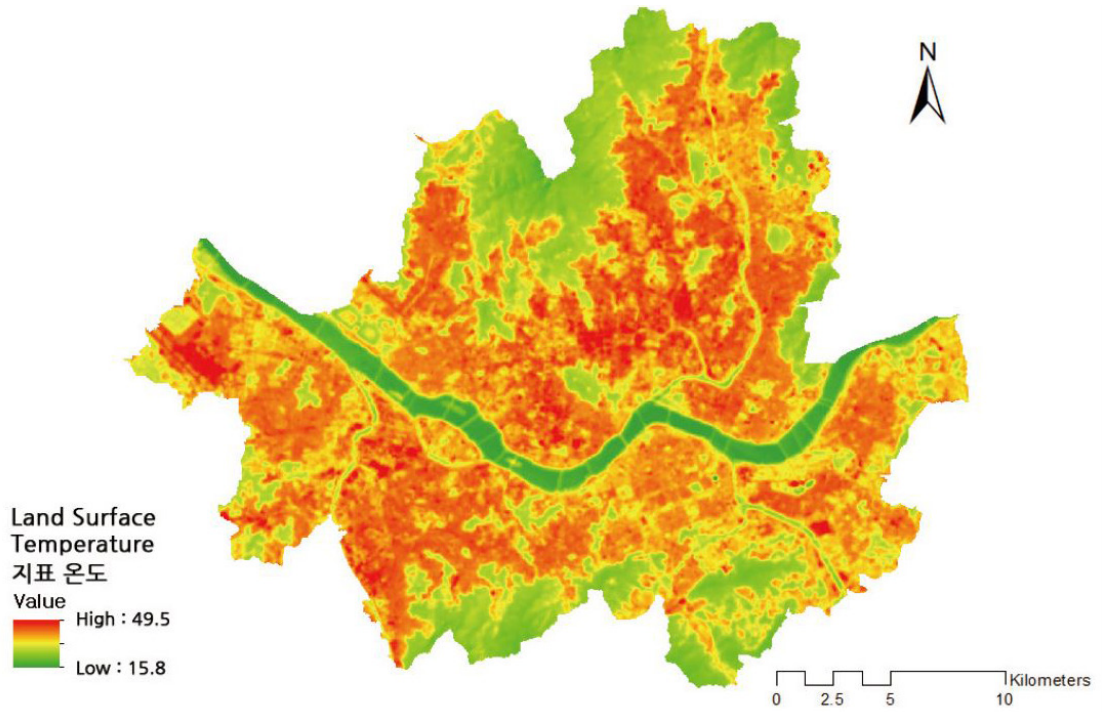


Figure 4 : Land Surface Temperature distribution in Seoul, 2016.05.16

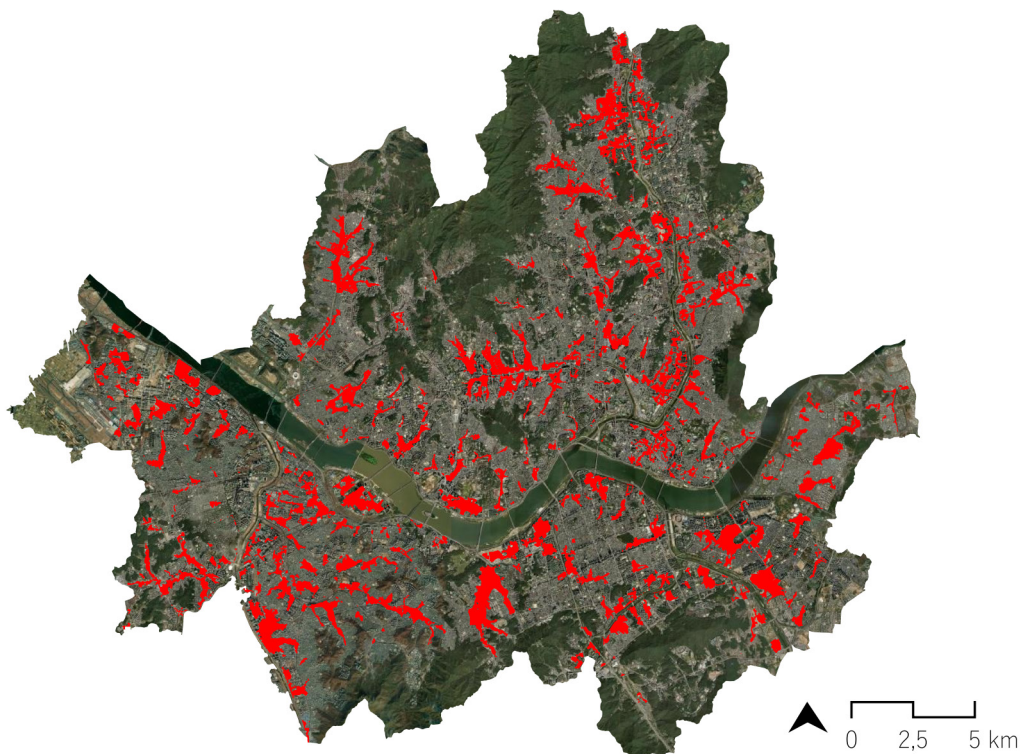


Figure 5 : Flood risk projection(~0.5m at 100mm/hr) of Seoul, 2023

## Societal

Waterfronts, especially riverfronts, continue to hold a high status as landmarks in the perception of Seoul's citizens (Figure 6); Hangang and Cheonggye stream (Ban & Kim, 2022) being the most famous and popular points of destination. Recently, urban streams are gaining popularity as spaces for recreation and to escape urban heat stress (S. E. Kim et al., 2023). This is related to the global trend that has followed the COVID-19 pandemic, through which people have rediscovered the value of these blue-green open spaces (J. Kim et al., 2023; Ugolini et al., 2020). The fact that current mayor Oh Sehoon continues to promote the concept of 'Great Hangang Project' and 'Waterside City' (Seoul Metropolitan Government, 2023a; Water Circulation Safety Bureau, 2025) serves to illustrate the demand for urban waterfronts is far from declining.

However, due to the severe and conspicuous consequences brought by climate change (Figure 7 and 8), these demands will soon begin to include certain climate adaptive capacities. According to the KMA(Korean Meteorological Administration) Weather Data Service (2026) the number of high-intensity rainfalls have been steadily increasing in South Korea, along with the number of hot days(over 33°C) and tropical nights(over 25°C) in Seoul. Corresponding to this trend, a recent report published by The Seoul Institute (M. Kim, 2025) points to the government's acknowledgement of waterfronts' potential to mitigate heat waves and flash floods and proposes design strategies that could help waterfronts cope better with anticipated challenges caused by climate change. However, linking waterfront design and climate change is only in its beginning phase and fails to include contextual conditions. This study will contribute to making climate adaptivity a more relevant topic in the discourse of waterfront design in the near future.



Figure 6 : Bulgwang stream Cherry blossom festival 2022.04.09

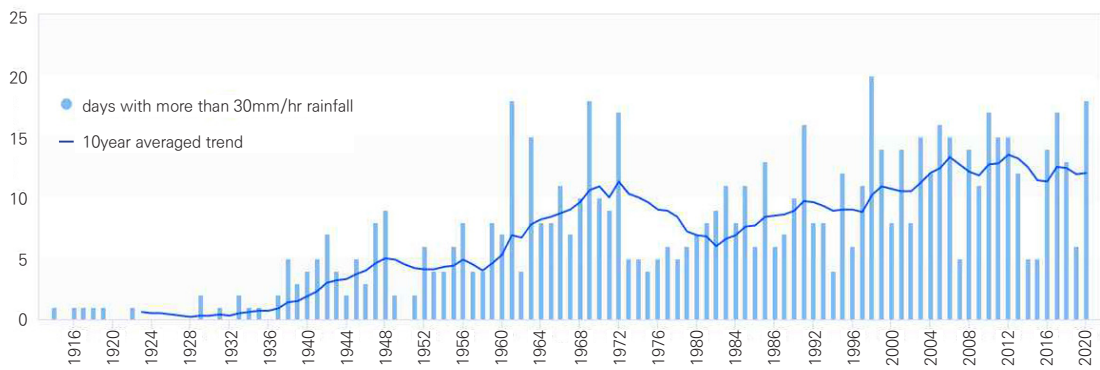


Figure 7 : 1975-2025 Trend of heavy rainfall frequency in South Korea (Presidential Water Commission, 2020)

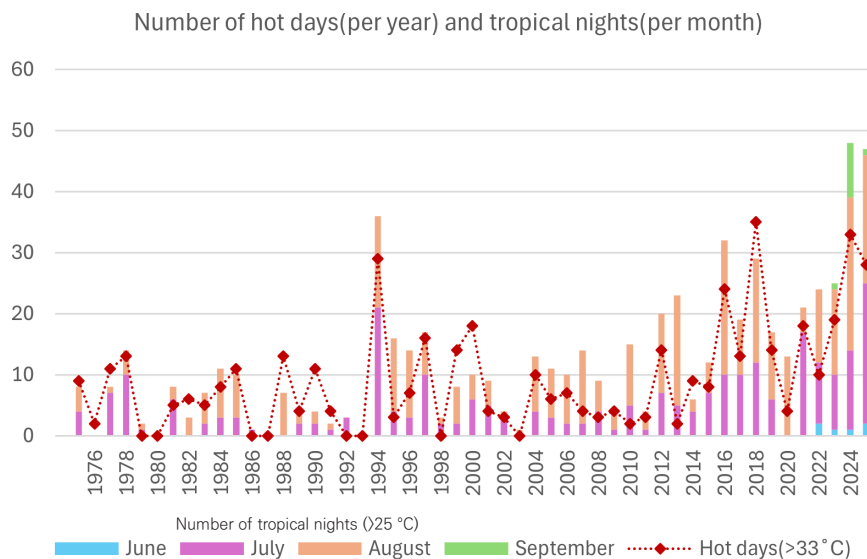


Figure 8 : 1975-2025 Trend of heat waves in Seoul

## 1.5 Scope

Out of 61 waterways<sup>1</sup> in Seoul, 5 of them were selected for this study: Hangang river and four district streams flowing into it (Figure 11). The four streams that all extend towards the boundary of Seoul's administrative boundary are Hongje, Jungrang, Anyang and Tan, and all together they run through<sup>2</sup> 16 districts out of 25 in Seoul. Hangang river is 1,155m wide on average and its waterfront consists of 4 river parks on the north and 5 on the south, where those on the same side are interconnected.

This study focuses on a limited timespan: a four-month window from June to September. Traditionally, summers in Korea are marked by two climatic events: monsoon during mid-June and typhoons in mid-September signaling the beginning and the end respectively. During the three-month duration, temperature typically peaked during July and August. However, recent trends in Seoul suggest that summers are being extended into four months (Figure 9 and 10) with elongated periods of monsoon and heatwaves. This study assumes that such a trend will continue and is set on a four-month window instead of three.

The design outcome of this study is limited to three waterfronts whose specific locations are given as examples of generating design variations as result of the proposed framework. Furthermore, the scope of design is restricted to public space interventions that can be implemented by governmental bodies. Open spaces which are state-owned such as streets, waterfronts, and parks are primarily considered. However, plots that are more appealing for public intervention than private development due to their small size -recycling garbage dump sites, old factories inside residential districts, parking lots- were also taken into account.

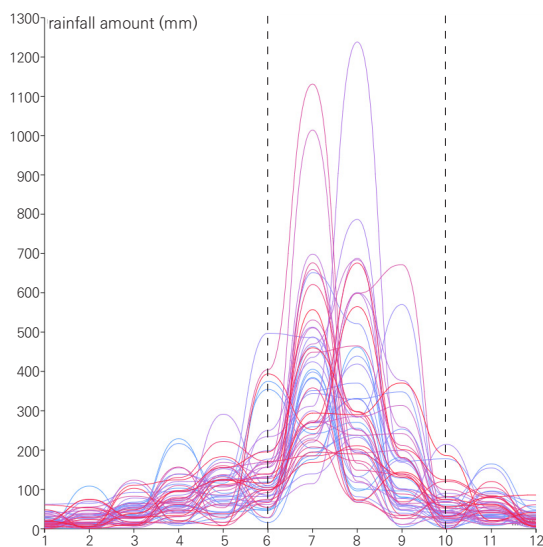


Figure 9 : 1975-2025 Monthly rainfall in Seoul

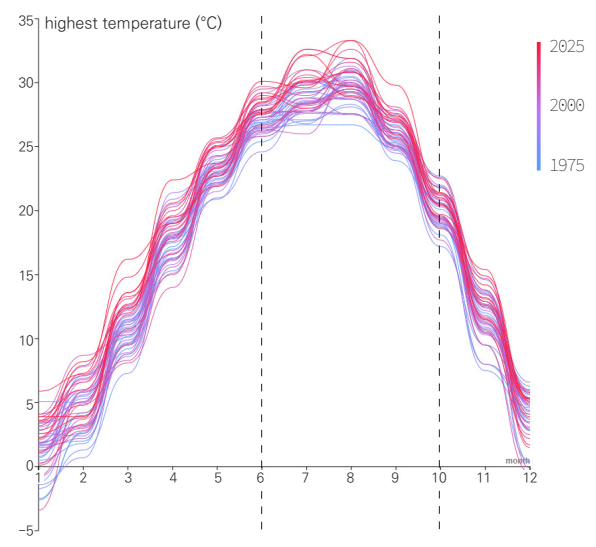


Figure 10 : 1975-2025 Monthly highest temperature in Seoul

1 According to Environment Action Association (<https://ecowater.or.kr/>), Seoul consists of 1 river, 4 district streams and 56 tributaries.

2 Or rather 'run by', as these streams are often the administrative boundary between districts.

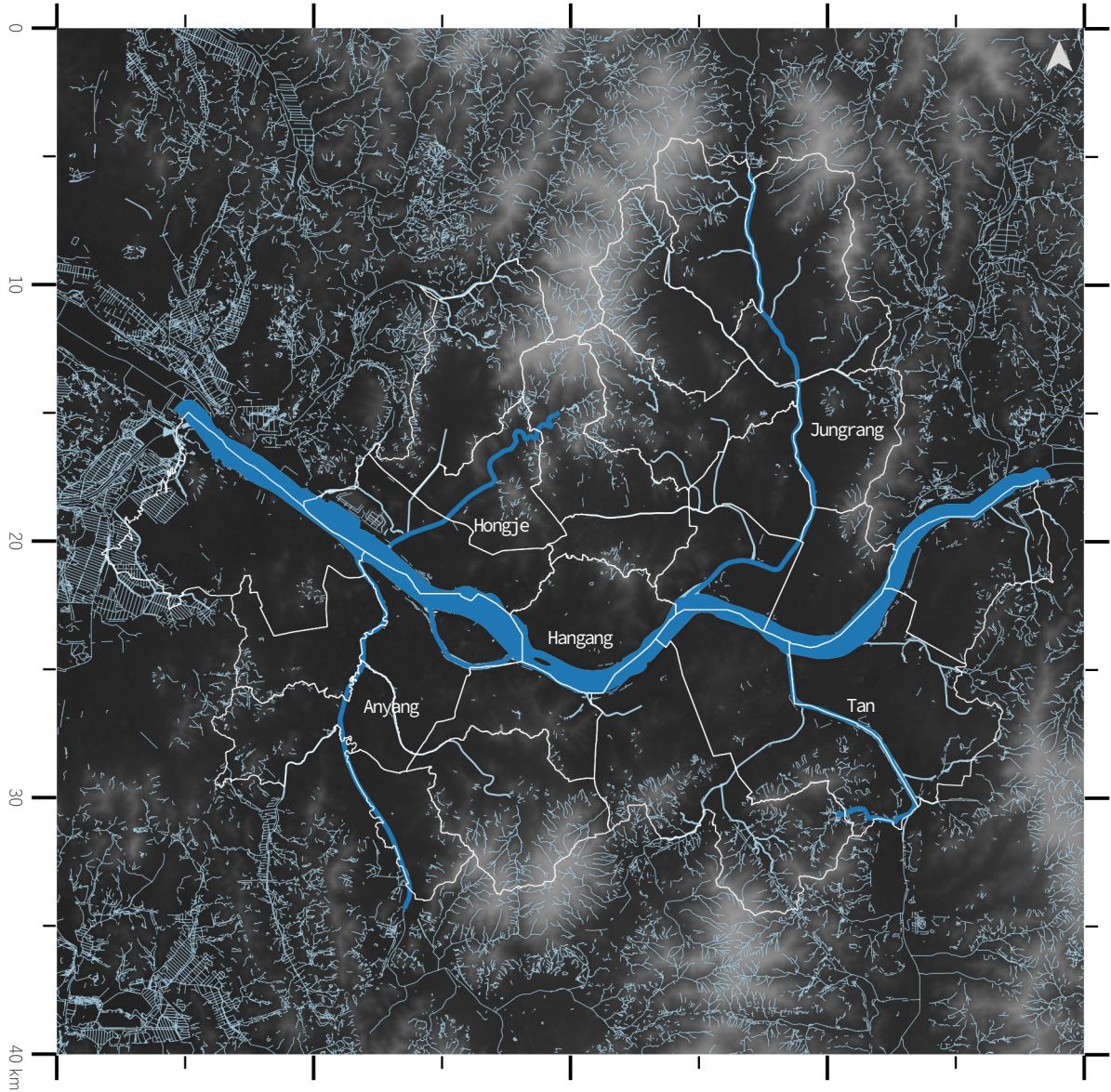
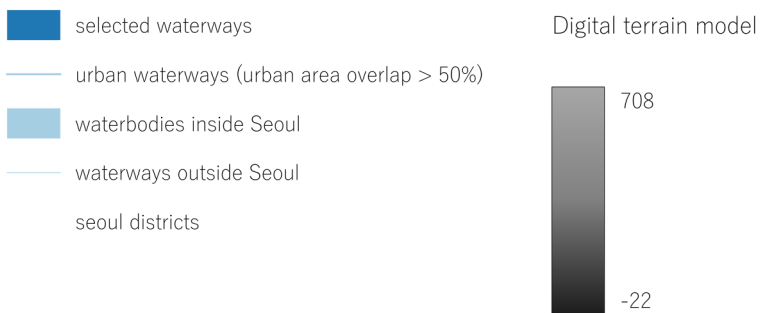


Figure 11 : Five selected waterways with district boundaries



## **Part 2 Approach**

2.1 Conceptual framework	20
2.2 Theoretical framework	21
2.3 Scalar framework	26
2.4 Methodology	28

Three frameworks structure this study: conceptual, theoretical, and scalar. The first explains the conceptual structure of this study. The second framework is centered around the concept of environmental urban morphology and its application on Seoul's waterfronts during extreme summers. The last framework explains how this study differentiates two different spatial scales when the variables defined in the theoretical framework are examined.

## 2.1 Conceptual framework

Figure 12 summarizes the study conceptually and illustrates the structure of the whole project. As shown below, the objective is to define the link between the morphology of waterfronts and daily life. Climate adaptive performances of the waterfronts, derived from their geometric and mobility network properties, were used as the lens to make this correlation clearer. Climate change that exacerbates heat waves and flash floods is the context that fortifies the relevance of this study.

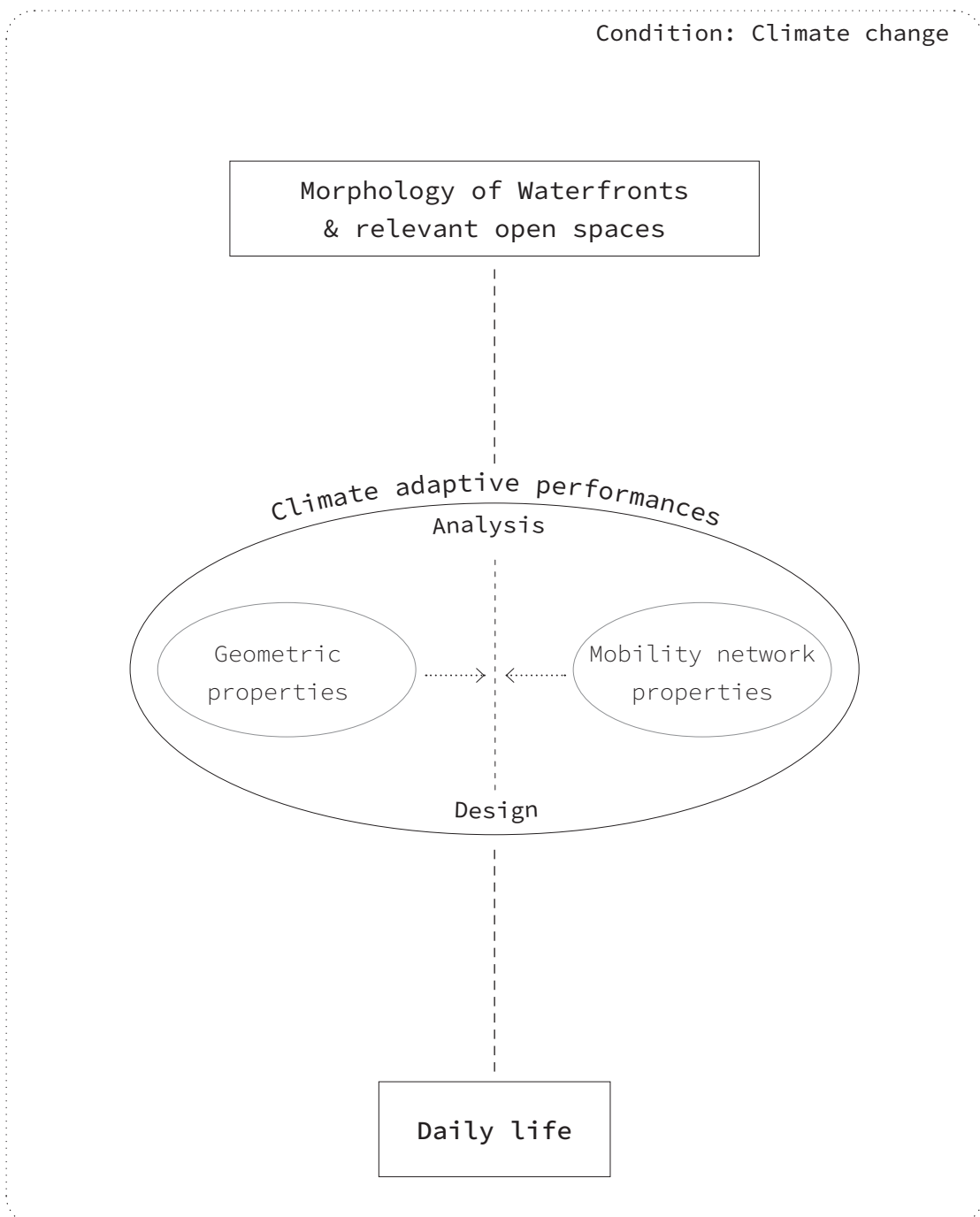


Figure 12 : Conceptual framework

## 2.2 Theoretical framework

The theoretical framework of this study is founded on the reconstruction of the concept of environmental urban morphology, a multidisciplinary approach that links open space morphology with daily life trajectories (Maretto et al., 2023). Application of this approach to the climate adaptivity of Seoul’s waterfronts during extreme summers resulted in four spatial variables as shown in Figure 13: flood and heat mitigation of waterfronts, mobility disruption by floods and cooling opportunity accessibility. The former two approach climate adaptivity through geometrical properties, whereas the latter two employ network analysis. The following literature review examines relevant studies conducted on environmental urban morphology, which is an overarching concept, and the four variables that resulted from its application to Seoul’s waterfronts.

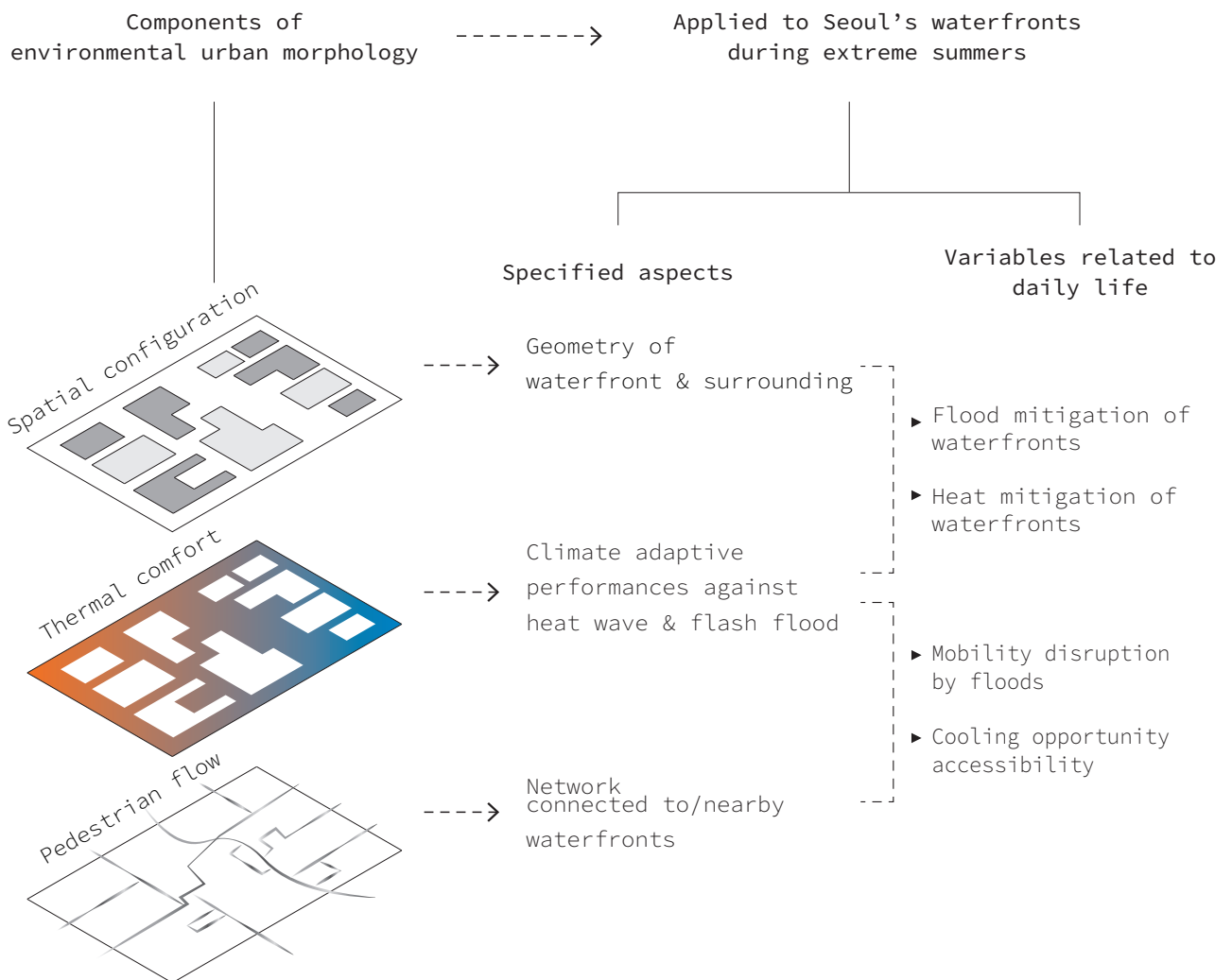


Figure 13 : Structure of theoretical framework-Environmental urban morphology’s application to Seoul’s waterfronts

## Environmental urban morphology

This concept was first introduced to identify the relationship between the geometric characteristics of open space and microclimates (Adolphe, 2001). Later it evolved into methodologies to analyze and design open spaces. While Zhang & Liu (2021) proposed a parametric design tool that could improve microclimatic conditions by modifying the formal characters of streets and plazas, Maretto et al. (2023) added a third variable—the trajectories of daily life. The multidisciplinary method that comprehensively analyzes public spaces in dense urban settings is strengthened by this third layer. Overlaid pertinence strips, functional analysis, pedestrian flow, and microclimatic conditions were presented to better inform designers and decision makers of how spatial interventions could alter various aspects of daily life. In this study, the overlay is conducted with hierarchy to identify correlations between Seoul's waterfronts and daily life through their climate-adaptive capacities.

## Heat mitigation of waterfronts

Relationship between the spatial characteristics of urban areas and heat has been investigated with diverse perspectives and methods. Since most indicators of heat are quantifiable, many researchers have employed regression models to quantify the contribution of certain spatial variables such as pervious area ratio, building height, sky view factor, or volume porosity. Such studies conducted in various parts of the globe indicate that these correlations vary significantly depending on the climatic conditions and configuration of urban fabrics (Costa et al., 2024). Therefore, the papers reviewed for this study were limited to those conducted in South Korean cities.

Despite some debate over their extent, it has been proven that blue-green infrastructures substantially alleviate thermal discomfort in open spaces. A recent study that observed the Universal Thermal Climate Index (UTCI) fluctuation to indicate heat resilience of different Local Climate Zones (LCZ) in Seoul demonstrates well the impact and limitations of such unpaved areas (S. H. Kim et al., 2025). While 'green' LCZs performed notably better, they also manifested significantly larger standard deviations. This indicates that for open green spaces such as the waterfronts, other factors besides the spatial variables (such as orientation or wind direction and speed) included in the LCZ system play sizable roles in heat resilience. However, ample evidence supports the importance of these green and blue open spaces as critical cooling urban spaces. An urban stream and its surrounding green surfaces in Daejeon (Park et al., 2012) exhibited 2 to 3°C lower surface temperature compared to urban areas. Another that study focused on generic spatial attributes independent of the LCZ system (S. H. Kim et al., 2025) stressed the importance of extended provision of green surfaces to reduce air temperature in the same city.

## Flood mitigation of waterfronts

Study on urban flood mitigation performance of open spaces is often limited to Urban Green Spaces (UGS) and their ability to reduce surface runoff. This approach falls under the perspective of Nature Based Solutions (NBS) where these landscaped open spaces are integral components of Green Infrastructures. Together with waterbodies such as rivers or ponds, they are expected to reduce surface runoff by temporarily storing runoff water or absorbing them (Ferreira et al., 2021). While this emphasis on UGS's ability reduce flood risk resulted in various perspectives in investigating their spatial contributions (Razzaghi Asl & Pearsall, 2023; Yang & Kim, 2024; W. Zhang et al., 2025), semi-grey open spaces such as Seoul's waterfronts have not received much attention: roughness and pervious pavement are the only links through which these spaces are incorporated in NBS.

In the case of Seoul, more serious implications are expected of this knowledge gap. Every summer, the city experiences flash floods caused by heavy rainfalls whose number and intensity have been rising over the last five decades (Yoon et al., 2016). When NBS is applied to Seoul, small-scale interventions such as green roofs are prioritized (J. Kim et al., 2022) due to limited availability of UGS in this dense and privatized city. In face of such challenges, Seoul City has recently decided to resort to construction of underground storage tunnels (Bae, 2011) regarding which questions have been raised concerning the extent of their effectiveness, as well as their applicability all over the city (J. Kim et al., 2024). It is crucial for densely built cities such as Seoul that this knowledge gap in semi-grey infrastructure NBS should be resolved.

### **Cooling opportunity accessibility**

Physical accessibility represented as a space-temporal concept is essential in understanding the trajectories of daily life (Ellegard, 1999), especially for evaluation of essential public services (Verlinghieri & Schwanen, 2020) such as provision of cooling urban refuges. While variables such as physical distance, cost and socio-personal perceptions can be used to analyze different aspects of accessibility to certain places, chrono-urbanism (Hussein, 2025) aims to accurately model how people move in the city by viewing space as time-based opportunities. Consequently, it is closely associated with distributional justice of essential services and is often used to evaluate the geographic allocation of public functions (Aranguren et al., 2023; Kondrateva et al., 2017); especially for people moving by foot or public transport. When applied to Seoul's waterfronts during heatwaves, their limited number and location of entry points imply a strong impact of physical accessibility on environmental justice.

### **Mobility disruption by floods**

Flood damage assessment on mobility networks is typically conducted by delineating hazardous areas under several certain flood scenarios, classifying vulnerability of urban areas and calculating the extent of the damage according to each scenario (Rebally et al., 2021). It can be conducted in different spatial scales varying from neighborhood to regional, which illustrates the wide spectrum of disruptions that can be caused by floods (Arrighi et al., 2019; Lee et al., 2020; Yao et al., 2026). Indicators of disruption used in different studies also vary from movement speed, inundation depth and water flow velocity, depending on the climate and street configuration of chosen sites. Among various methods, calculation of edge or node centrality based on network theories has been applied to assess the temporary city-wide disruption on mobility infrastructures (Rebally et al., 2021). This focus on centrality implies that some road segments can cause severe disruptions on the whole network, affecting the trajectories of daily life all over the city. This is in line with Seoul's experience with flash floods where some neighborhoods become more immobilized than others and some waterfronts cause traffic disruption on the whole city (Jung & Bae, 2025).

## **2.3 Scalar framework**

This section explains which spatial scales are applied to the variables mentioned in the theoretical framework and why. First, the reasons for implementing the scalar framework on the climate adaptive performances are given. Next, how the variables—each related to sub-question 2a to 2d—are differentiated into two spatial scales is explained.

### **Necessity of multi-scalar perspective**

Cooling impact and flood vulnerability of a waterfront have different implications depending on which spatial scale they are observed with. This relationship between the performances in different scales also point to different trajectories of daily life. For example, if a waterfront is significantly cooler than urban areas reachable by metro, but not much difference is detected when compared to its nearby neighborhoods, it implies that city-wide visiting demand will be higher than local demands during heat waves. Additionally, if the local pedestrian network remains intact when a waterfront is flooded, but serious city-wide disruptions are caused in the motorways, it would indicate long-distance travelers will be more affected. Therefore, imbalance between different scales points to problems of equity and effective distribution of services. In this study, thermal relief, thermal refuge accessibility, and mobility robustness under flood are the three variables that are examined through this multi-scalar lens that differentiates local and city-wide implications.

### **Multi-scalar variables and sub-questions**

The variables were differentiated in two spatial scales except for flood mitigation. This exception which was translated into a waterfront's ability to withhold runoff water in sub-question 2a is irrelevant to spatial scale. The remaining three variables that each correspond to sub-question 2b to 2d were all calculated in two versions. Together, the seven variables serve as basis for evaluation and classification of Seoul's waterfronts (Figure 14).

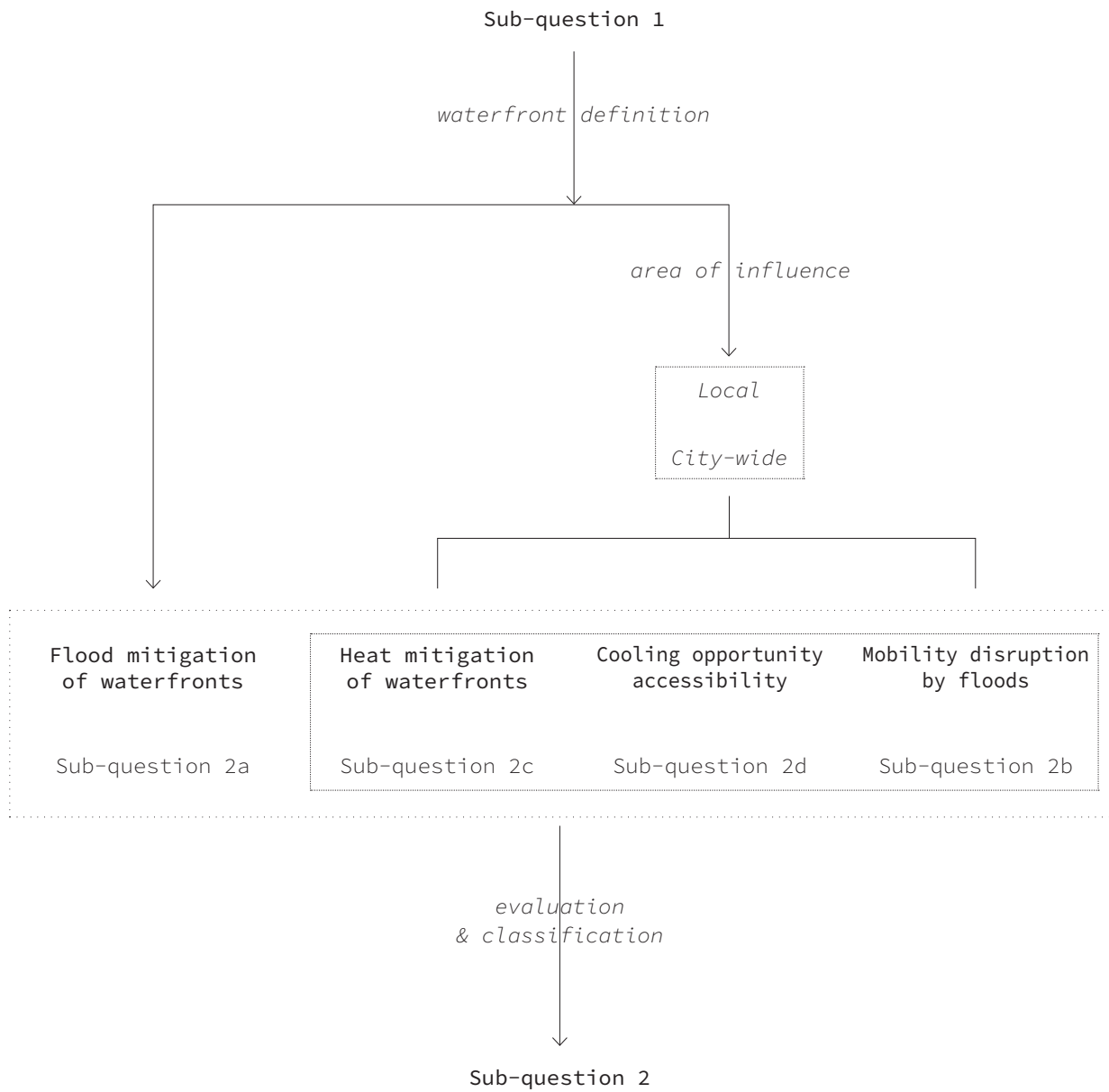


Figure 14 : Application of spatial framework on research questions

## 2.4 Methodology

Table 01 shows a summary of methods used to answer the research sub-questions. Programs and programming languages used in the methods are explicitly given. QGIS was mainly used for network-related algorithms and production of maps. GRASS GIS was only used for identification of catchment basins. Algorithms written in R and Python played key parts in answering sub-questions 1, 2a, and 2c.

Table 01: Summary of methods used in the study, in relation to research sub-questions

Research question	
<p><b>Sub-question 1</b></p> <p><i>What is the spatial extent of a waterfront in Seoul, and the area of influence regarding heat waves and flash floods in the summer?</i></p>	
<p><b>Sub-question 2</b></p> <p><i>How can Seoul's waterfronts be evaluated and classified by spatial characteristics that affect daily life during extreme summers?</i></p>	
	<p><b>Sub-question 2a</b></p> <p><i>To what extent can waterfronts withhold floods during severe rainfalls?</i></p>
	<p><b>Sub-question 2b</b></p> <p><i>What is the extent of disruption on mobility networks when waterfronts become flooded?</i></p>
	<p><b>Sub-question 2c</b></p> <p><i>What is the extent of thermal relief provided by the waterfronts, compared to their surrounding urban area during heat waves?</i></p>
	<p><b>Sub-question 2d</b></p> <p><i>What is the level of accessibility to waterfronts that provide refuge from heat waves?</i></p>
<p><b>Sub-question 3</b></p> <p><i>Which design principles derive climate adaptive solutions that enhance quality of daily life trajectories from spatial analysis?</i></p>	
<p><b>Sub-question 4</b></p> <p><i>How can the proposed framework generate site-specific design interventions which stakeholders can evaluate and choose from?</i></p>	

*How can spatial impacts of Seoul's waterfronts on climate adaptivity be measured and leveraged to enhance trajectories of daily life?*

Methods		
<b>Waterfront segmentation</b> -Based on break of pedestrian continuity -Waterfront and local area definition written in R		<b>QNEAT Iso-Area (QGIS)</b> -City-wide area definition -Metro stops accessible within 20min
<b>Relative weighing system</b> -Weigh variables calculated from sub-question 2a to 2d		<b>Qualitative classification</b> -Compare butterfly graphs
<b>IDF - Hyetograph conversion</b> -Alternating block sequence	<b>Watershed analysis</b> -Catchment basin calculation using GRASS GIS	<b>Overflow simulation</b> -Based on morphology focused model -Simulation written in Python
<b>PST analysis (QGIS)</b> -Network betweenness & angular choice -Mobility robustness under flood		
<b>Proxy air temperature</b> -Morphological contribution to air temperature -Kernel operation for 30 x 30m pixels (Python)		<b>Normalize relative difference</b> -Proxied air temperature difference -Variable to represent demand to cool down
<b>Isochrone overlapping (QGIS)</b> -Pedestrian cathment area(PCA) of waterfront entry points -Last-mile PCA from nearest public transportation nodes		
<b>Operationalization of analysis</b> -Derive spatial elements to be leveraged -Identify effective intervention locations		<b>Relative weighing system</b> -Weigh design criteria as result of stakeholder negotiation  <b>Development of topological device</b> -Spatialize design elements according to site conditions

### 2.4.1 Sub-question 1 : Waterfront and area of influence definition

*What is the spatial extent of a waterfront in Seoul, and the area of influence regarding heat waves and flash floods in the summer?*

#### Waterfront segmentation

The spatial extent of a single waterfront in Seoul is based on their sunken profile (width) and usage (length). However, waterways were first filtered by two conditions: at least 30m wide to guarantee heat refuge functions (Y. Jiang et al., 2021) and at least 50% situated in urban areas - excluding forests and agricultural lands. Their widths were outlined by the border of adjacent roads or railways where the change of elevation began for the five chosen waterways. Their lengths were defined by points where pedestrian continuity is broken, but this was manifested differently between streams and the river. For streams, locations where the continuity of their promenades were broken by convergence with another waterway were the first points of segmentation (Figure 15 - left). Crossings that only connect two opposite sides of the water inside an enclosed waterfront were discarded and only those that provided alternative routes besides the original promenade were considered. This first step is conceptually similar to delineation of urban river corridors by bridges (Forgaci, 2018), which is also founded on spatial perception of waterfronts and discards segmentation by paths that do not extend outside waterfronts. Given the distinct sunken condition of Seoul's waterfronts, elevated bridges that have limited impact on the promenades were also rejected in this study. The first round of segments were again divided into smaller pieces if people were forced to exit the enclosed space in certain points.

This method has several obvious shortcomings. Not all parts of the streams are completely flanked by roads or railways, which makes definition of waterfront boundaries difficult. Furthermore, this logic of segmentation may yield very short or long pieces that would not qualify as spatial unit based on usage. The difficulty rises in locations where waterways intersect, especially if one of them is significantly larger than another - as places where streams meet the river (Figure 16 - top). In these cases, the last pedestrian crossings where a person is forced to choose which riverfront they will travel to, were used as endlines of stream waterfronts.

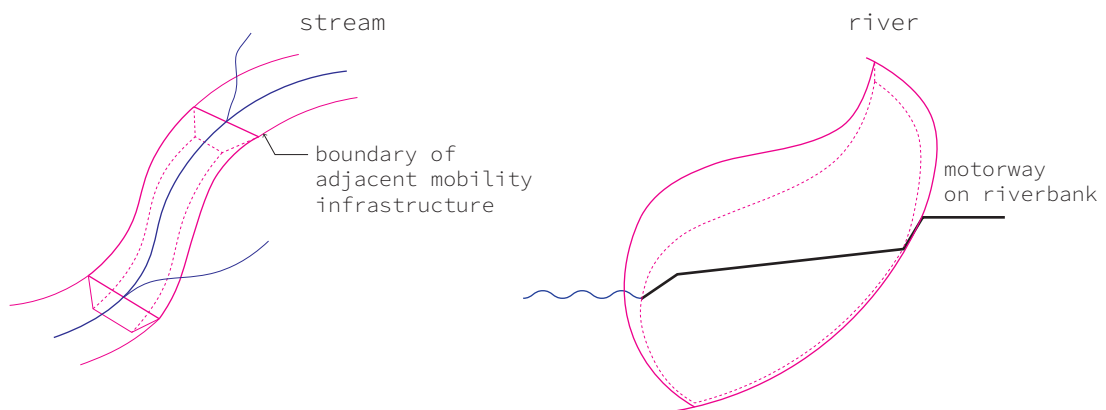
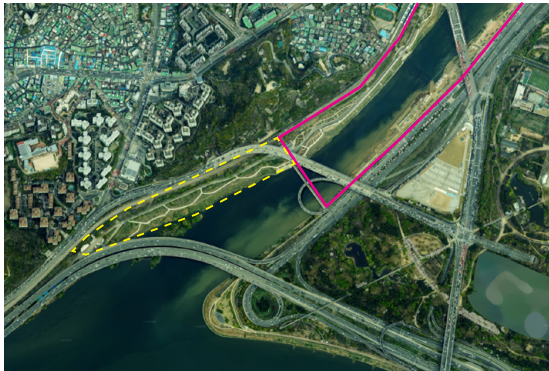


Figure 15 : Process of waterfront definition

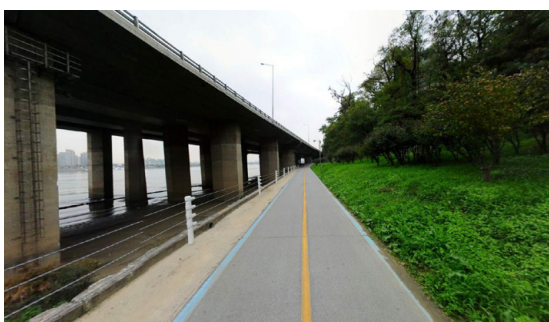
In the case of the river, only the designated Hangang parks within the first segments were recognized as waterfronts. The promenades that link the parks were disregarded in this study as they are no more than narrow passages that cannot provide climate adaptive functions that match up to the streams or river parks (Figure 16). In contrast to the stream waterfronts, these riverfronts are only half sunken; they are outlined linear pieces of land situated between a motorway sitting on a dike and a large body of water (Figure 15 - right). However, the spatial condition of being separated from its urban context by elevational change is fundamentally identical to the streams. In summary, waterfronts were segmented in points where the pedestrian continuity was broken by spatial configuration. This method that delineates waterfronts by usage based on spatial configuration is unlike most existing stream segmentation mechanisms which are founded on geomorphic, geo-climatic, hydraulic, or chemical characteristics (Melles et al., 2014).



Jungrang stream - Hangang river  
 intersection location : waterfront outline  
 in yellow is excluded



Example of river promenades between parks:  
 Promenade between  
 Hangang-4N and Hangang - 5N



Example of river promenades between parks:  
 Promenade between  
 Hangang-3S and Hangang - 4S

Figure 16 : Spaces excluded in waterfront definition in this study

### Local and city-wide area of influence definition

A waterfront's area of influence during heat waves and flash floods was differentiated in two spatial scales: local and city-wide. Since this study is focused on the open spaces related to the trajectories of daily life, these scales were based on the mode of transportation. Local scale was always based on pedestrian movement within potential 15 minutes from the waterfront (1km buffer area), identical for both heat waves and flash floods. However, the mode of transport was assumed differently for city-wide scale. Under heat waves, people's movement towards the waterfronts are investigated; and public transportation was considered over automobiles due to the lack of parking spaces reserved for waterfronts<sup>3</sup>. Therefore, accessible urban areas by metro within 24.28 minutes, which is the average travel time during weekends (STCIS(Seoul Transport Card Information System), 2026), were defined as the city-wide influenced area of waterfronts under heat waves (Figure 16). The metro stops were identified using QNEAT Iso Area plugin in QGIS. In the case of flash floods, the focus of this study was on assessing the disruption on people's capacity to move. Therefore, the spatial influence was assumed to be much more extensive than the case of heat waves, and the automobile network of the whole city was simulated for damage assessment.

This delineation of local areas by buffering 15-minute(1km) walking distance from waterfront boundaries has several expected limitations. For example, some local areas are bound to include other waterfronts. It does not take in block configuration of other strong spatial borders such as railways or highways within the area, which significantly reduces the physical connection to waterfronts. However, such complexities were not considered in this study and were left to be discussed in section 4.2.

3 Except for Hangang river parks where each have several parking lots; however, even for them the available number is significantly lower than the demand. For example, the total number of visitors in July 2025 in Yeouido park was 1,302,955 while 1,782 parking spaces was provided to accommodate 153,655 cars (한강공원 [Hangang Park], 2026c, 2026a, 2026b).

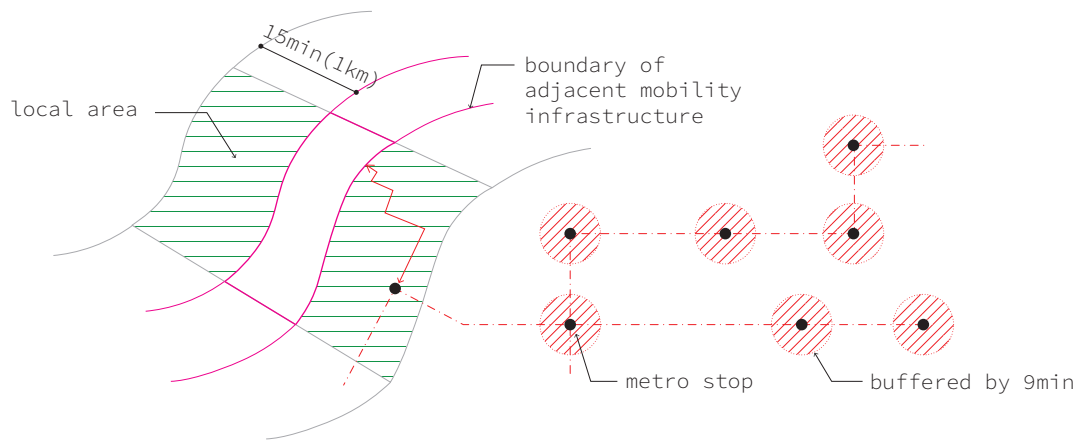


Figure 17 : Locally influenced area of 15min potential aea and city-wide influenced area during heatwaves

### 2.4.2 Sub-question 2 : Evaluation and classification of waterfronts

*How can Seoul's waterfronts be evaluated and classified by spatial characteristics that affect daily life during extreme summers?*

#### Relative weighing system & Qualitative classification

Evaluation of waterfronts was conducted by normalization of seven spatial variables that each represent a waterfront's certain performance under flash floods or heatwaves. The process of defining each variable is elaborated in detail through the answers given for sub-question 2a to 2d. These normalized variables were then weighed based on their relative impact on daily life. The combined effect of these seven normalized and weighted variables was used to qualitatively group the waterfronts into several types. Figure 17 summarizes the process.

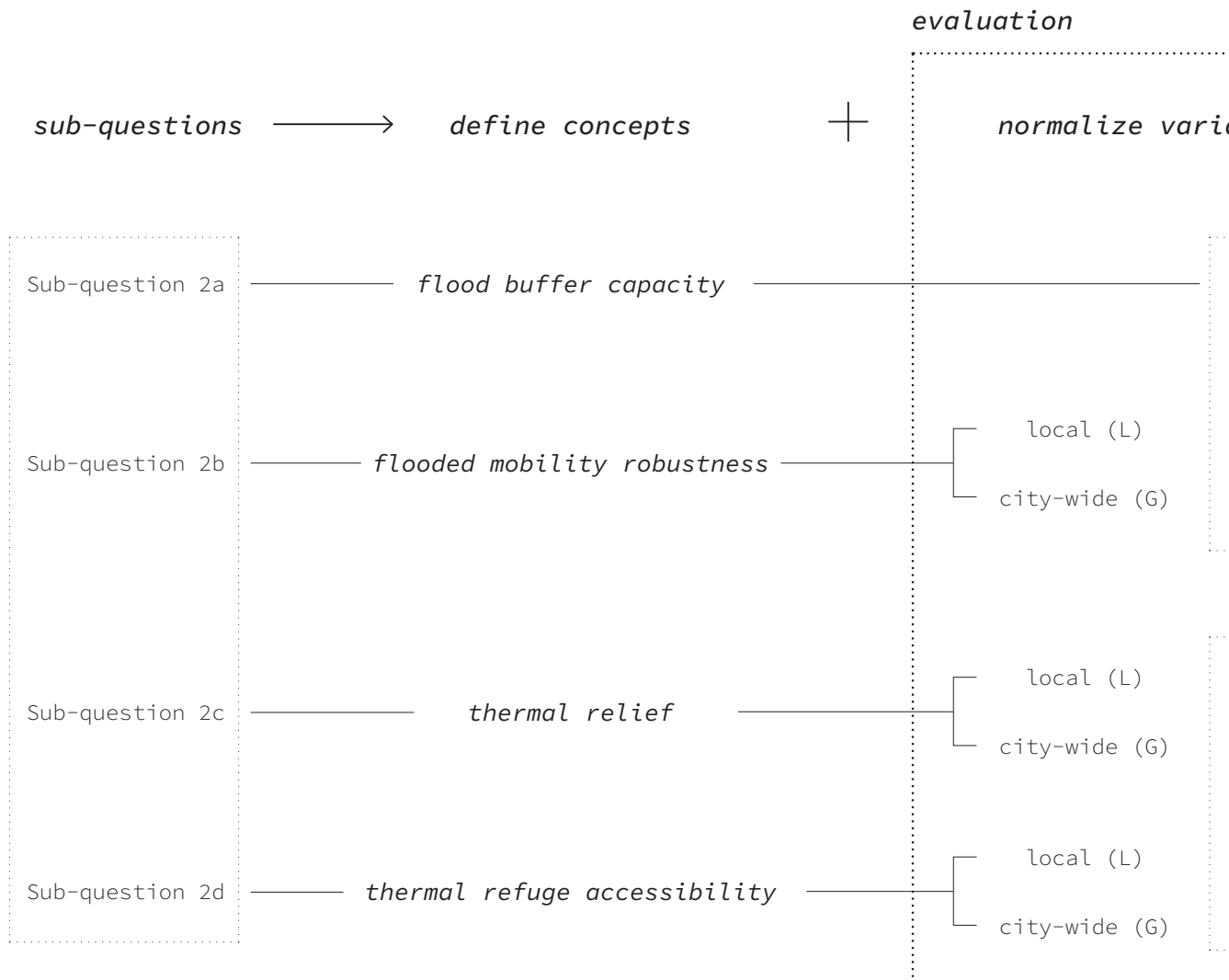
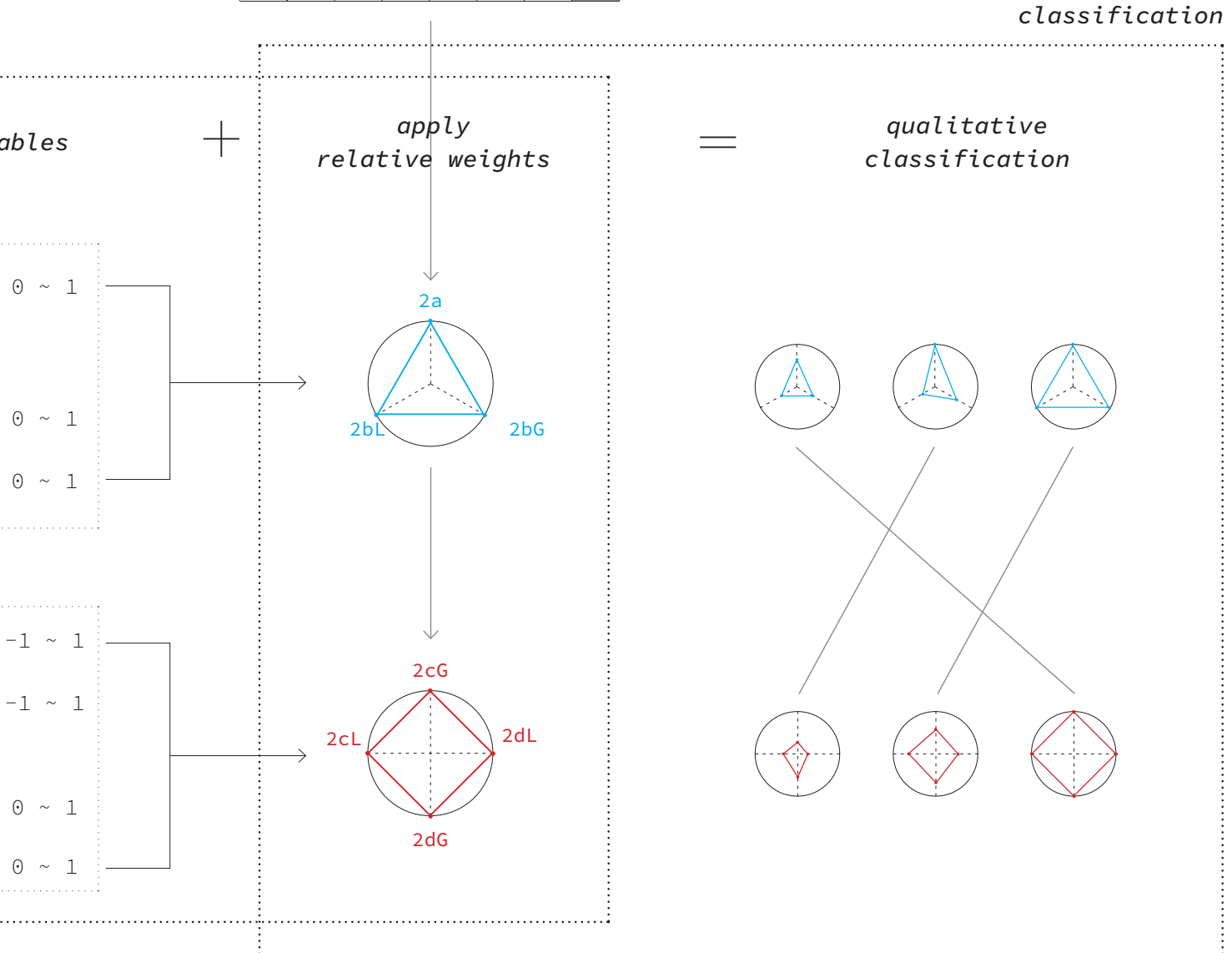


Figure 18 : Structure of evaluation and classification of waterfronts in this study

	a	bL	bG	cL	cG	dL	dG
a							
bL							
bG							
cL							
cG							
dL							
dG							



### 2.4.3 Sub-question 3 : Calculation of flood buffer capacity

*To what extent can waterfronts withhold floods during severe rainfalls?*

#### Overflood Simulation

Calculation of a waterfront's ability to withhold flood was conducted on a simulated rainfall event of 30-year frequency projected by a probabilistic study of rainfall intensity (Yoon & Choi, 2019). The applied peak intensity is 113.7mm, which is higher than Seoul's current standard for preventive measures (94.3mm). As shown in Figure 19, the intensity-duration-frequency(IDF) curve calculated by Yoon & Choi(2019) was converted into a 24-hour hyetograph according to the Alternating Blocks Method (Elfeki, 2025). Catchment basin whose runoff water flows into each waterfront was computed in GRASS GIS watershed analysis, based on the SRTM digital terrain model of 30m resolution. For each waterfront, catchment basins and tributary waterways were assigned throughout Seoul (Figure 20). Event-based flood buffering capacity of a waterfront is defined as

$$1 - \frac{\sum_t Vol_{overflow}}{\sum_t Vol_{inflow}}$$

where  $\sum_t Vol_{inflow}$  (m<sup>3</sup>) is the total input volume of water flowing into the waterfront and  $\sum_t Vol_{overflow}$ (m<sup>3</sup>) is the total volume of water that overflowed from the waterfront. When  $Q_{in}(t)$  (m<sup>3</sup>/hr) is the flow rate of runoff water that flows into the waterfront from its corresponding basin at hour  $t$ , the variable is equal to

$$1 - \frac{\sum_t Vol_{overflow}}{\sum_t Q_{in} \times \partial t}$$

$Q_{in}(t)$  (m<sup>3</sup>/hr) is then defined as

$$Q_{in}(t) = I_{rainfall}(t) \times \sum_i Runoff_i \cdot A_i$$

$I_{rainfall}(t)$  (m<sup>3</sup>/hr) is the rainfall intensity at hour  $t$ ;  $A_i$  (m<sup>2</sup>) is area of surface type  $i$  inside the given basin (Figure 19); and  $Runoff_i$ <sup>4</sup> is the corresponding runoff rate of surface type  $i$ .

Return Period(Year)	Duration(hr)										
	1	2	3	6	9	12	15	18	24	48	
10	89.3	139.8	183.0	249.0	288.9	309.6	346.5	367.2	415.2	528.0	
20	103.9	162.4	208.2	289.2	332.1	355.2	405.0	417.6	475.2	600.0	
<b>30</b>	<b>113.2</b>	<b>176.2</b>	<b>223.2</b>	<b>316.2</b>	<b>358.2</b>	<b>386.4</b>	<b>436.5</b>	<b>450.0</b>	<b>513.6</b>	<b>638.4</b>	
50	121.7	194.2	245.4	342.6	396.0	436.8	481.5	504.0	571.2	696.0	
80	132.4	211.2	269.7	365.4	435.6	488.4	537.0	563.4	631.2	753.6	
100	139.4	219.4	279.9	376.2	448.2	516.0	564.0	594.0	662.4	782.4	
200	161.9	250.8	310.2	412.2	487.8	574.8	636.0	714.6	763.2	878.4	

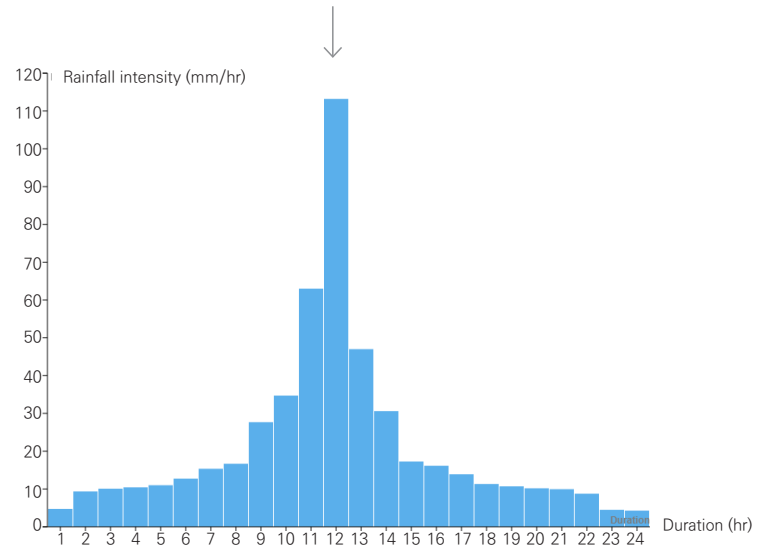


Figure 19 : IDF(Intensity-Duration-Frequency) curve conversion to 24hour hyetograph



Figure 20 : Catchment basins included in this study

To calculate the overflow volume  $Q_{out}(t)$  (m<sup>3</sup>/hr), the volume of water discharged from the waterfront at time  $t$  must also be defined. This can be done assuming the cross section area of the discharge point  $S_{discharge}$  (m<sup>2</sup>) is known and mean flow velocity  $v(t)$  (m/hr) is calculated using Manning's coefficient with  $n = 0.014$  (for untreated concrete), slope  $i$  and hydraulic radius  $R$  (m).

$$Q_{out}(t) = v(t) \cdot S_{discharge}, \quad v(t) = \frac{1}{n} R^{\frac{2}{3}} \sqrt{i}$$

While the maximum storage volume of a waterfront can be calculated by its known sections and total length, the stored water volume (m<sup>3</sup>) at hour  $t \geq 2$  is

$$Vol_{storage}(t) = \min [Vol_{max\ storage}, Vol_{storage}(t-1) + Q_{in}(t-1) - Q_{out}(t-1)]$$

with base case  $Vol_{storage}(1) = 0$ . Then remaining storage volume at time  $t$  is

$$Vol_{max\ storage} - Vol_{storage}(t-1)$$

Finally, the overflow volume at hour  $t$  is equal to

$$Vol_{overflow}(t) = \max [0, Q_{in}(t) - Q_{out}(t) - \{Vol_{max\ storage} - Vol_{storage}(t-1)\}]$$

which is conceptually equivalent to (total inflow - discharge - remaining volume). The whole process is summarized in Figure 21.

However, this definition of flood buffer capacity is only applicable to the most upstream waterfront segment with no other inflow except for its drainage area. For waterfront segments downstream, the  $Q_{out}(t)$  (m<sup>3</sup>/hr) of upstream waterfront must be added as inflow from upstream segment at hour  $t$ ,  $Q_{upstream\ inflow}(t)$  (m<sup>3</sup>/hr) (Figure 21).

This calculation is based on a simplified model that relies on several assumptions. Most importantly, fluvial rise of water is completely excluded, and the artificial drainage systems are also overlooked. The rainfall event simulation prioritizes city-scale spatial conditions and assumes all runoff inside a drainage area flows into the waterfront. Furthermore, the rainfall is assumed to occur simultaneously in Seoul and contained inside the city. The latter assumption results in disregarding upstream inflow from suburban regions. Lastly, the 24 hour hyetograph converted from an IDF curve is not tailored to simulate a typical severe rainfall event during monsoon season in Korea, which have been projected to demonstrate heavier hourly intensities (Seo et al., 2025).

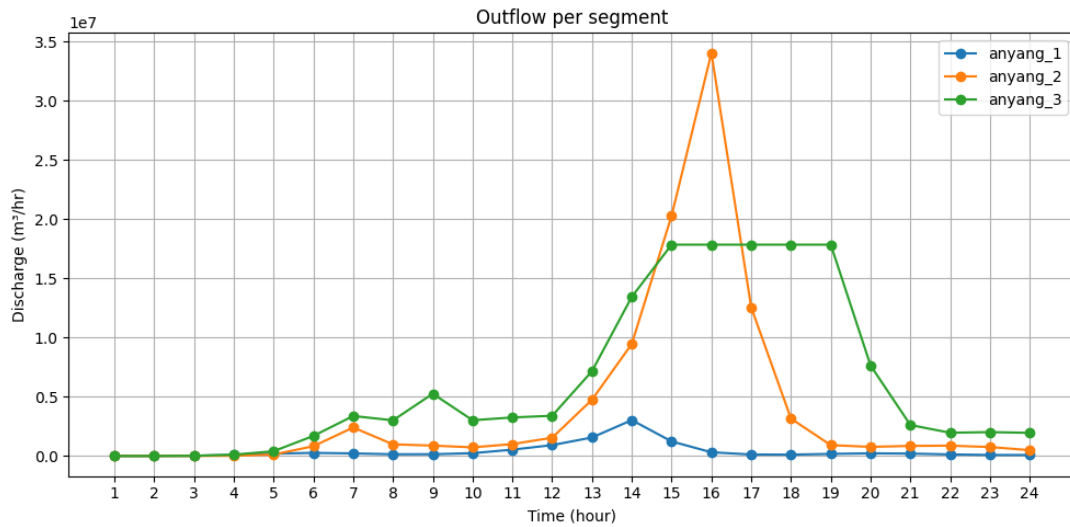
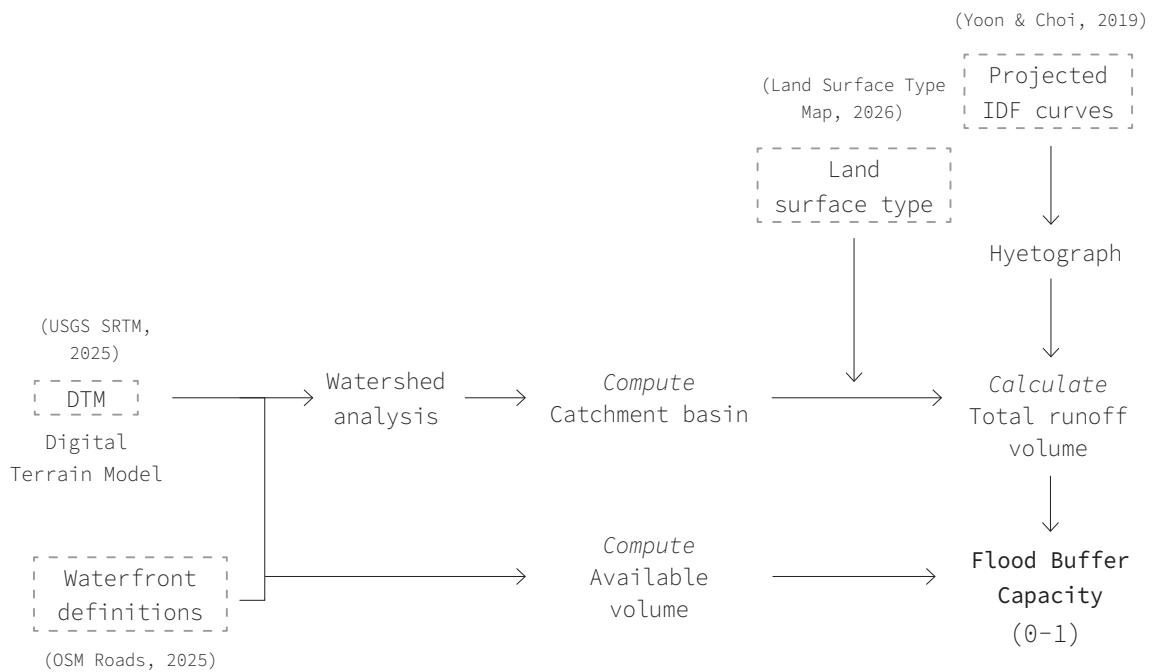


Figure 21: Discharge flow rate of Anyang's waterfronts during simulated rainfall



[ ]: Input datasets

Figure 22 : Flood buffer capacity calculation process

#### 2.4.4 Sub-question 2b : Calculation of flooded mobility networks

*What is the extent of disruption on mobility networks when waterfronts become flooded?*

##### PST analysis

The robustness of flooded mobility networks was assessed by comparing the total traffic capacity of the flooded state with the original state (Kermanshah & Derrible, 2017). This variable points to the level of intactness a mobility network would sustain through an overflow of a waterfront at its lowest bank level. Therefore, this variable should be considered together with the flood buffer capacity, which points to the likelihood of a waterfront to be flooded. The process is summarized in Figure 24.

The capacity in local scale is assessed by summing up the total angular choice values weighted by the segment lengths of the pedestrian network. In QGIS, PST was run with a 20-degree angle and 1km walking distance for the whole city for different flood scenarios, including the normal unflooded state. Afterwards, the simulated networks were clipped with 15-minute buffered areas of the waterfronts were according to their lowest bank levels (Figure 22).  $\sum_{1km} \text{Angular Choice} \cdot \text{Length}_{flooded\ scenario}$ , which is the sum of angular choice values weighted by the length of paths is then compared to the original sum under normal state  $\sum_{1km} \text{Angular Choice} \cdot \text{Length}_{normal\ state}$

$$\text{Local Flooded Mobility Robustness} = \frac{\sum_{1km} \text{Angular Choice} \cdot \text{Length}_{flooded\ scenario}}{\sum_{1km} \text{Angular Choice} \cdot \text{Length}_{normal\ state}}$$

Identical logic was implemented for the city-wide analysis but using network betweenness instead of angular choice for automobile network. Bridges and tunnels were assumed to be never flooded to yield conservative results. The network betweenness was computed for an inclusive region that expands outside the city by 5km and then clipped by the administrative city boundary (Figure 23). In this case, the sum of network betweenness weighted by the width<sup>5</sup>,  $\sum_{city} \text{Network Betweenness} \cdot \text{Width}_{flooded\ scenario}$  of the roads was calculated for each flood scenario and its ratio to the normal state  $\sum_{city} \text{Network Betweenness} \cdot \text{Width}_{normal\ state}$  was calculated as below.

$$\text{City – wide Flooded Mobility Robustness} = \frac{\sum_{city} \text{Network Betweenness} \cdot \text{Width}_{flooded\ scenario}}{\sum_{city} \text{Network Betweenness} \cdot \text{Width}_{normal\ state}}$$

This method of computing the sum of network-related variables with width or length and investigating their distribution in different scenarios have been conducted to assess network disruption at city-scale (Casali & Heinimann, 2019). Variations have been tested to assess network resilience (Abenayake et al., 2022) or to identify road segments that will experience most stress during floods (Huang, 2021). Application of network analysis on Seoul's mobility network which are frequently adjacent to waterfronts is therefore an effective way of determining their impact on daily life trajectories during flash floods.

However, flooded mobility robustness is based on a simple and unrealistic model that may exaggerate the impact of the waterfronts. Identical to the flood buffer capacity, the simulation assumed that a single rainfall occurs uniformly inside the city, thus an overflow of a waterfront signifies that other waterfronts with same or lower bank levels will also be flooded simultaneously. Furthermore, as the flood scenarios are based on the lowest bank level of the waterfronts, this variable is more likely to amplify their geographic importance, since the magnitude of disruption is likely to be higher for upstream segments.

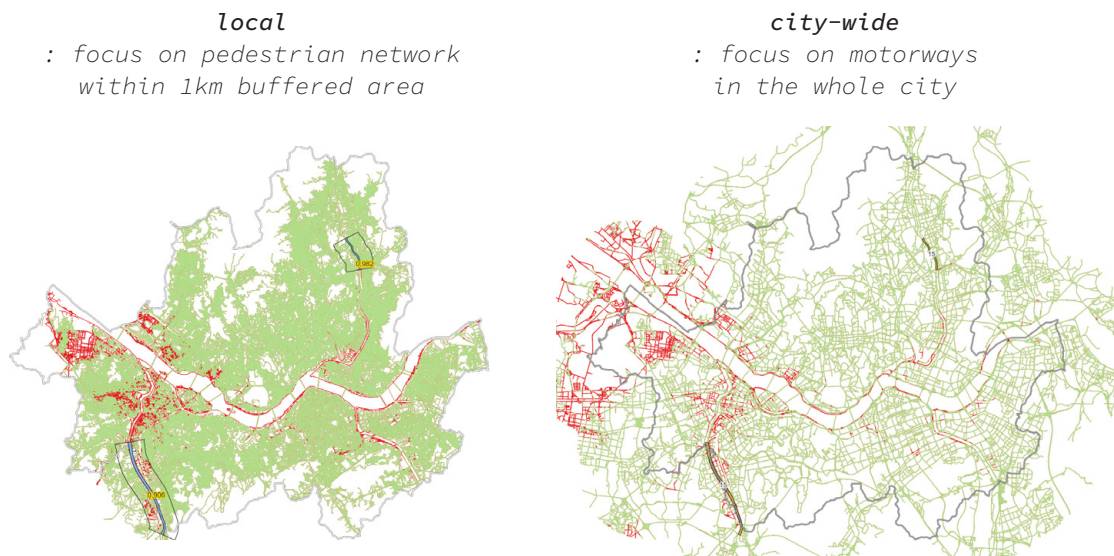


Figure 23 : Simulated mobility networks and areas of influence for local and city-wide scale

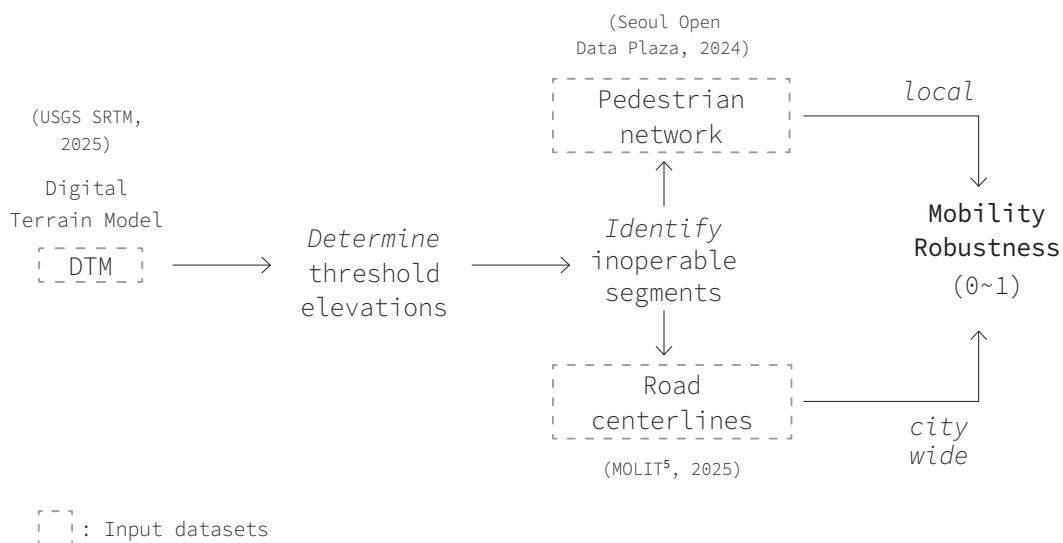


Figure 24 : Flooded mobility robustness calculation process

5 Link-Node dataset provided by the Ministry of Land, Infrastructure and Transport comes with number of road lanes. Width was calculated by multiplication of 3m on this value.

### 2.4.5 Sub-question 2c : Calculation of thermal relief

*What extent of thermal refuge do the waterfronts provide to their surroundings?*

#### Calculation of relative heat mitigation through spatial factors

The purpose of this index is to measure the attractiveness of spatial conditions inside the waterfronts under heat waves. Due to lack of sensors inside the sites, there are currently limited ways to estimate thermal relief; most studies therefore resort to land surface temperature (R. Jiang et al., 2021; Park et al., 2012). Recently, the installation of S-DOT stations in Seoul that track air temperature every hour has provided more reliable indicators of thermal comfort in dense urban settings. Kim et al. (2025) used this data to prove that land use, sky view factor, built area ratio, and volumetric porosity demonstrated high impact on mean daytime air temperature in Seoul. The resulting coefficients and buffer radius of each variable<sup>6</sup> were used in this study to proxy air temperature of the whole city.

$$H_{unit} = \sum \alpha_i \cdot Landuse_i + \beta \cdot SVF + \gamma \cdot BAR + \varepsilon \cdot VP$$

$H_{unit}$  is the spatial contribution to air temperature;  $\alpha_i$  is the coefficient of land use type  $i$ ,  $\beta$  is the coefficient for sky view factor (SVF),  $\gamma$  is the coefficient for built area ratio (BAR), and  $\varepsilon$  is the coefficient for volumetric porosity (VP).  $H_{unit}$  was calculated for every 30m-by-30m pixel of the whole city, which were then converted into  $ZH_{unit}$ , to normalize their distribution. Next, they were shifted to transform into positive values.

$$ZH_{unit} = \frac{H_{unit} - Mean_{seoul}}{Std_{seoul}} + abs[\min(\frac{H_{unit} - Mean_{seoul}}{Std_{seoul}})]$$

Finally, for each waterfront and its target area  $ZH_{unit}$  values were averaged and calculated as below to represent its relative attractiveness during heat waves.

$$Thermal\ Relief = \frac{Avg\ ZH_{urban\ area} - Avg\ ZH_{waterfront}}{Avg\ ZH_{urban\ area} + Avg\ ZH_{waterfront}}$$

The lowest index -1 would indicate that the target area was the coolest places to be found in Seoul, while the highest index +1 would indicate the same for the waterfront. The previous process which ranks the  $H_{unit}$  through normalization inside a given area is an important step without which the baselines of thermal relief index would not exist.

This variable is manifested in two spatial scales: local and city-wide (Figure 25). For local scale, 1km buffered area defined in sub-question 1 was the target urban area. For city-wide scale, pedestrian catchment areas of 600 meters around metro stations reachable in 24.28 minutes were calculated. Each spatial and temporal threshold in this case was set according to data addressing the pedestrian catchment area of Seoul's metro stations (Lee et al., 2025) and travel time in the city during weekends (STCIS(Seoul Transport Card Information System), 2026). Only areas that exceed local thermal relief were included in the calculation for city-wide scale.

This method has several shortcomings in projecting the thermal comfort a waterfront offers. In case of heterogeneous urban areas, the averaged value is not sufficient to capture the actual air temperature people are exposed to while conducting their daily tasks. The effect of shade is reduced and only implied in certain morphological factors, consequently failing to differentiate distinct orientations of waterfronts. Furthermore, while air temperature is a better indicator of thermal comfort compared to surface temperature, its limited ability to represent heat stress or relief should be taken into account.

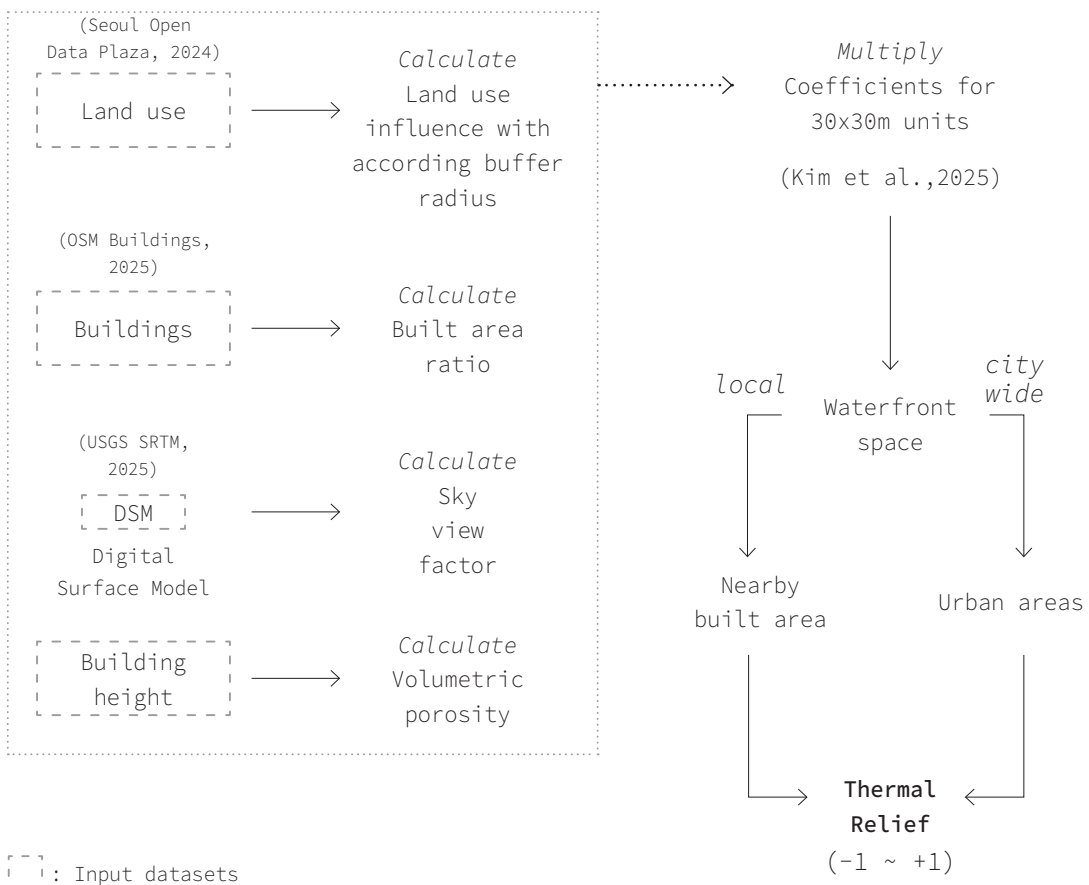


Figure 25 : Thermal relief calculation process

## 2.4.6 Sub-question 2d : Calculation of thermal refuge accessibility

*What is the level of accessibility to cooled down waterfronts?*

### Isochrone overlapping

Thermal refuge accessibility of a waterfront addresses the issue of reaching the waterfronts to seek refuge from heat waves. Therefore, this variable demonstrates the ease of realizing the demand to visit the waterfronts represented in thermal relief. Physical accessibility towards the waterfronts is illustrated as the areal ratio between potential coverage and actual coverage within a temporal limit (Figure 27). All isochrones were drawn in QGIS using the QNEAT Iso Area plugin and concave hull (threshold = 0.1). In local scale, sum of  $A_{\text{actual 15min coverage}}$  (m<sup>2</sup>), the area of 15-minute isochrones from the waterfront entrances is computed, and its ratio compared to the potential 15 minutes area  $A_{\text{potential 15min coverage}}$  (m<sup>2</sup>) is calculated (Figure 26 - left).

$$\text{Local Thermal Refuge Accessibility} = \frac{A_{\text{actual 15min coverage}}}{A_{\text{potential 15min coverage}}}$$

For city-wide scale, only the last-mile pedestrian routes from the last public transportation nodes are considered. Therefore, stops within nine minutes (the pedestrian catchment area of metro stations) of the waterfronts were identified, and the total area of corresponding isochrones from these stops were drawn. To give directionality, only areas that overlapped with 9-minute isochrones from the waterfronts' entrances were included in the actual coverage area from public transport to the waterfronts  $A_{\text{actual 9min public transport coverage}}$  (m<sup>2</sup>). Its ratio as part of  $A_{\text{potential 9min public transport coverage}}$  (m<sup>2</sup>), a 600m buffered area from the waterfronts is defined (Figure 26 - right) as

$$\text{City - wide Thermal Refuge Accessibility} = \frac{A_{\text{actual public transport coverage in 9min}}}{A_{\text{potential 9min coverage}}}$$

This method is in line with previous studies that computed physical accessibility based on chrono-urbanism (Jeon & Jung, 2023; Kolcsár & Szilassi, 2018). As heat refuge is only one of many ecoservices provided by urban green spaces, this variable provides one way of illustrating environmental justice based on physical accessibility (Jennings et al., 2012). However, as it only computes spatial coverage, it fails to include qualities that may vary in coverages; for example, the density of local areas included in the coverage is not considered, as well as the node centrality or number of available bus/metro lines are not included in the calculation.

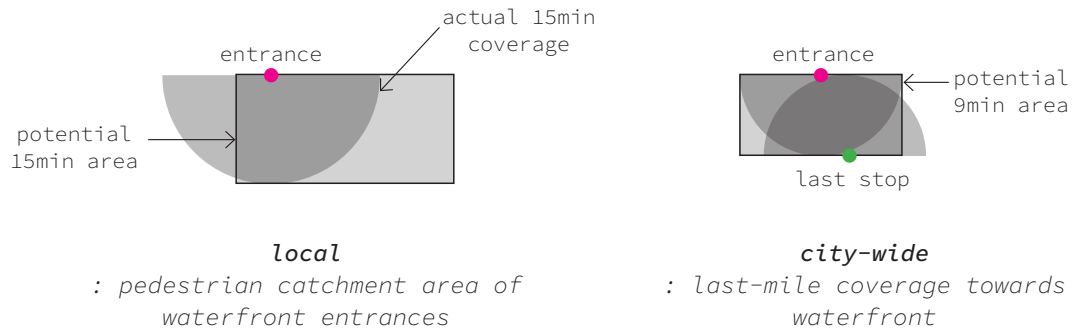


Figure 26 : Computed isochrones for thermal refuge accessibility in Hangang 1s

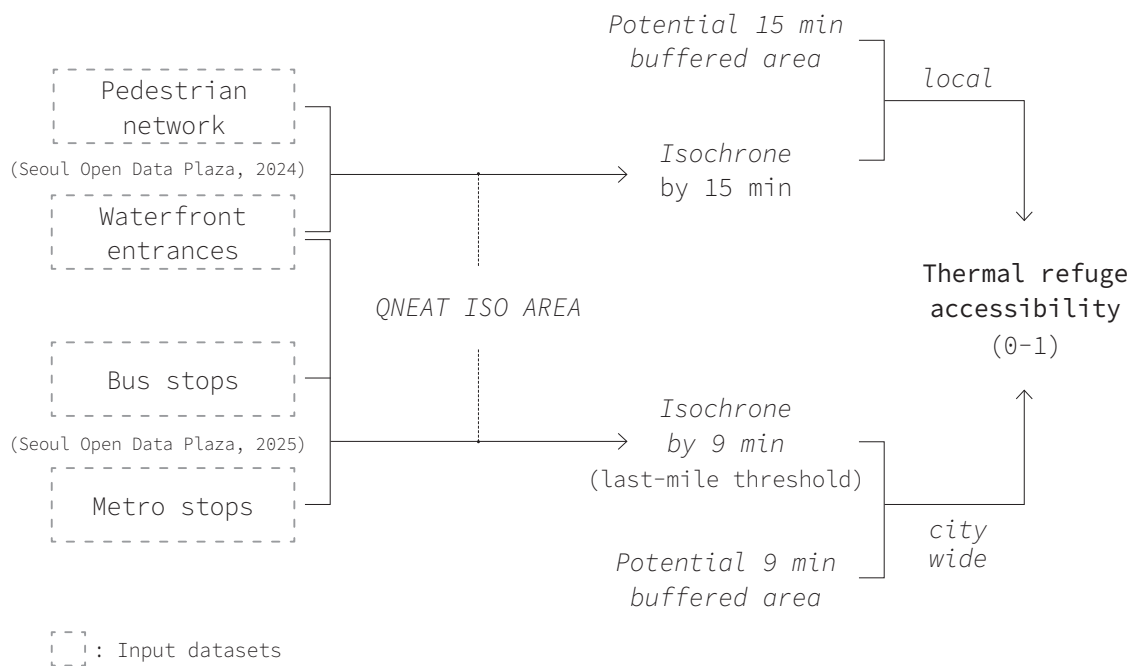


Figure 27 : Thermal refuge accessibility calculation process

### 2.4.7 Sub-question 3 : Design iterations on multiple sites + case studies

*Which design principles derive climate adaptive solutions that enhance quality of daily life trajectories from spatial analysis?*

Design principles were derived by multiple design iterations and case studies<sup>7</sup> with the objective to improve climate adaptive performances analyzed in the former sections (Figure 28). Case studies were focused especially in those from Japan and United States where waterfronts often neighbor large mobility infrastructures. Commonalities and potentials of design iterations were investigated first for each site and then for different waterfronts.

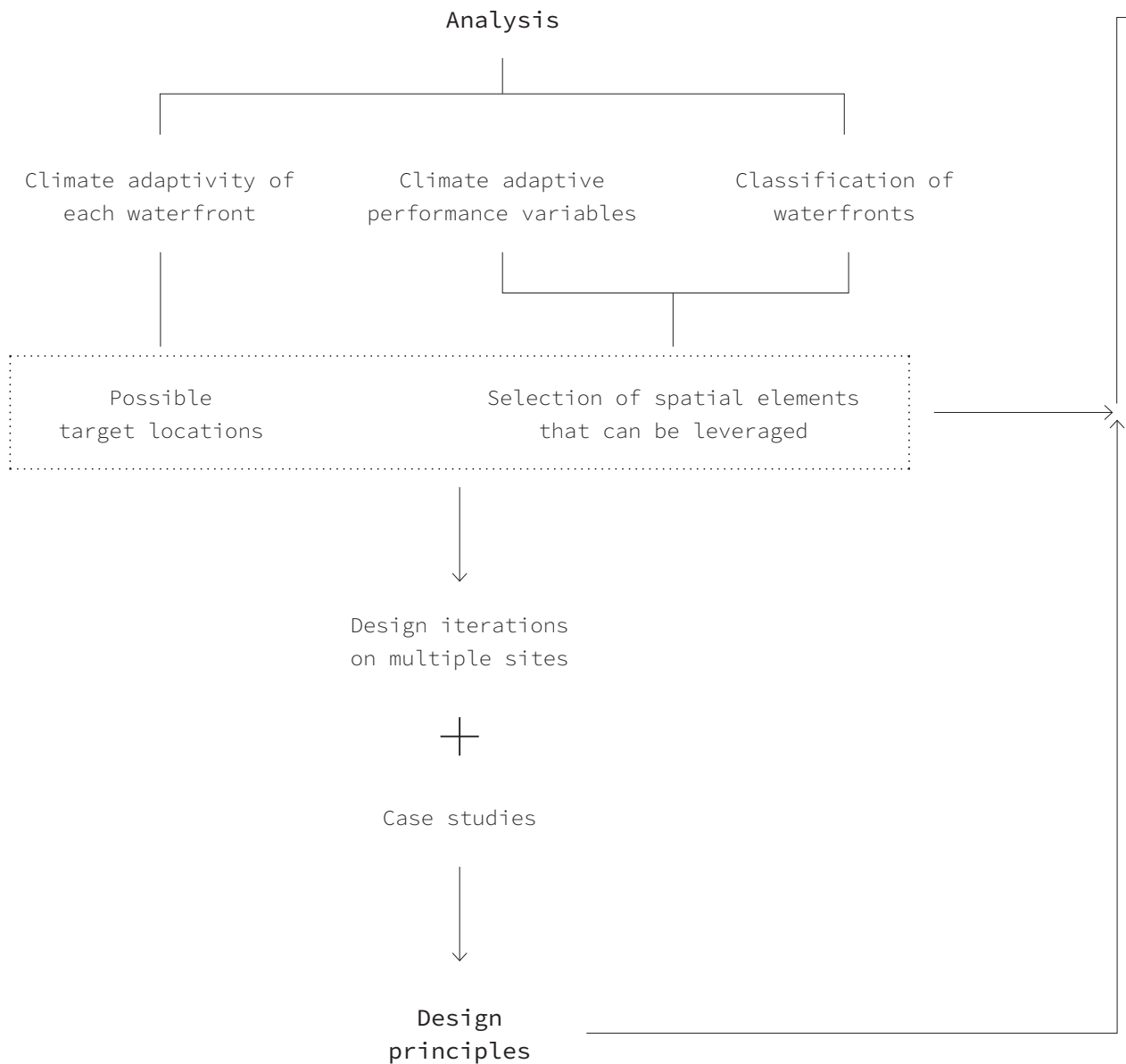


Figure 28 : Process of deriving design principles

#### 2.4.8 Sub-question 4 : Design iterations with rational approach

*How can the proposed framework generate site-specific design interventions which stakeholders can evaluate and choose from?*

The principles outlined in sub-question 3 were then synthesized with analysis results that point to effective locations and spatial elements. Again, design iterations were conducted, but in a more rationalized way (Figure 29). Topological devices were used to create variations of implementing spatial elements in given sites. These devices were products of urban scaffolding (Alexandrescu et al., 2016) that extract key spatial configurations between urban and natural spaces. For this study, a street-scale topological device was tailored for Seoul's waterfronts and their surroundings. AI X-Figura was used to visualize different design options using keywords from the topological device.

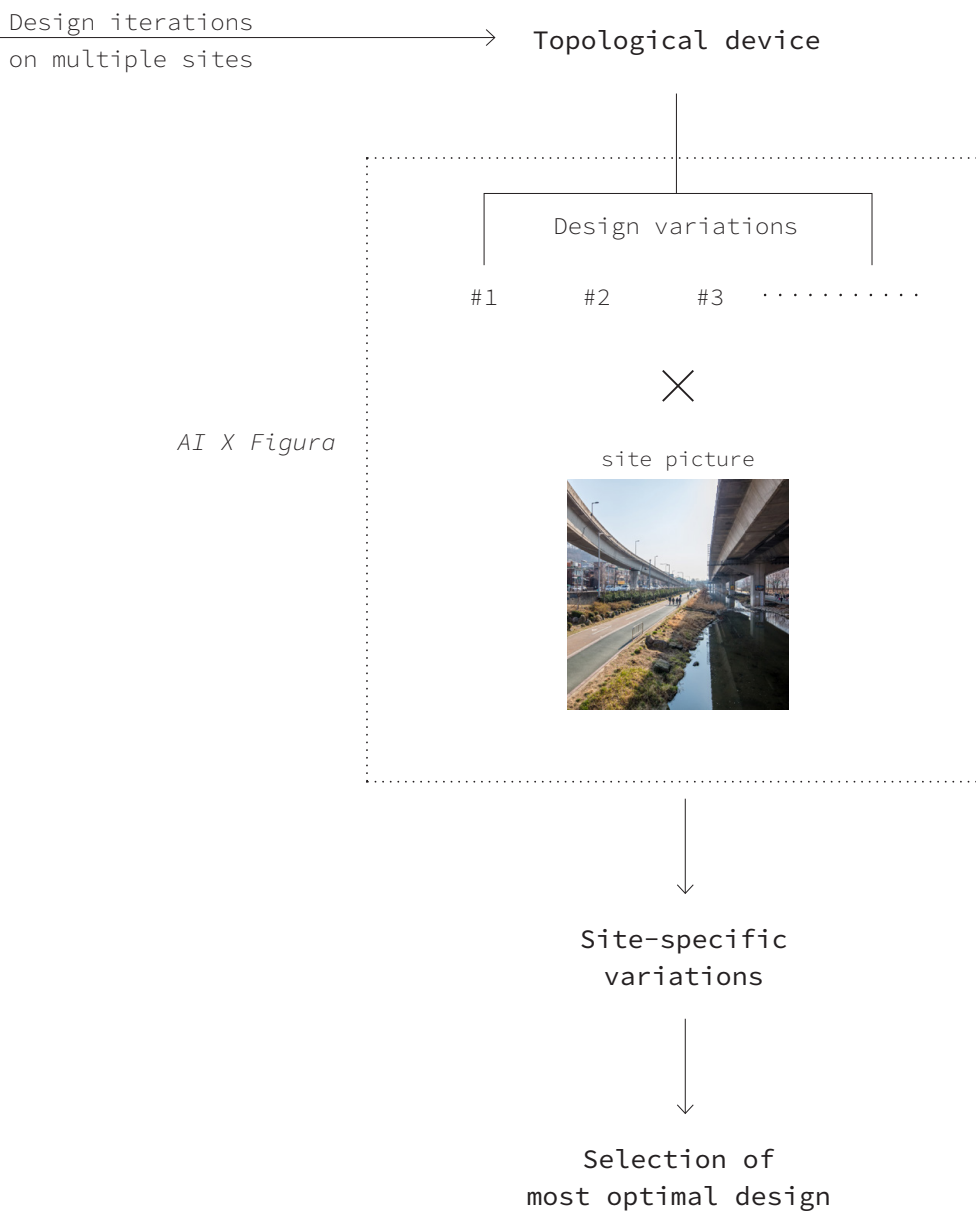


Figure 29 : Process of producing site-specific design variations

## **Part 3 Results**

3.1 Waterfront & areas of influence	50
3.2 Evaluation of waterfronts	56
3.3 Waterfront classification	62
3.4 Design principles	66
3.5 Design process	67
3.6 Implementation of developed process in real sites	74



### 3.1 Waterfront & areas of influence

#### 3.1.1 Waterfront definition

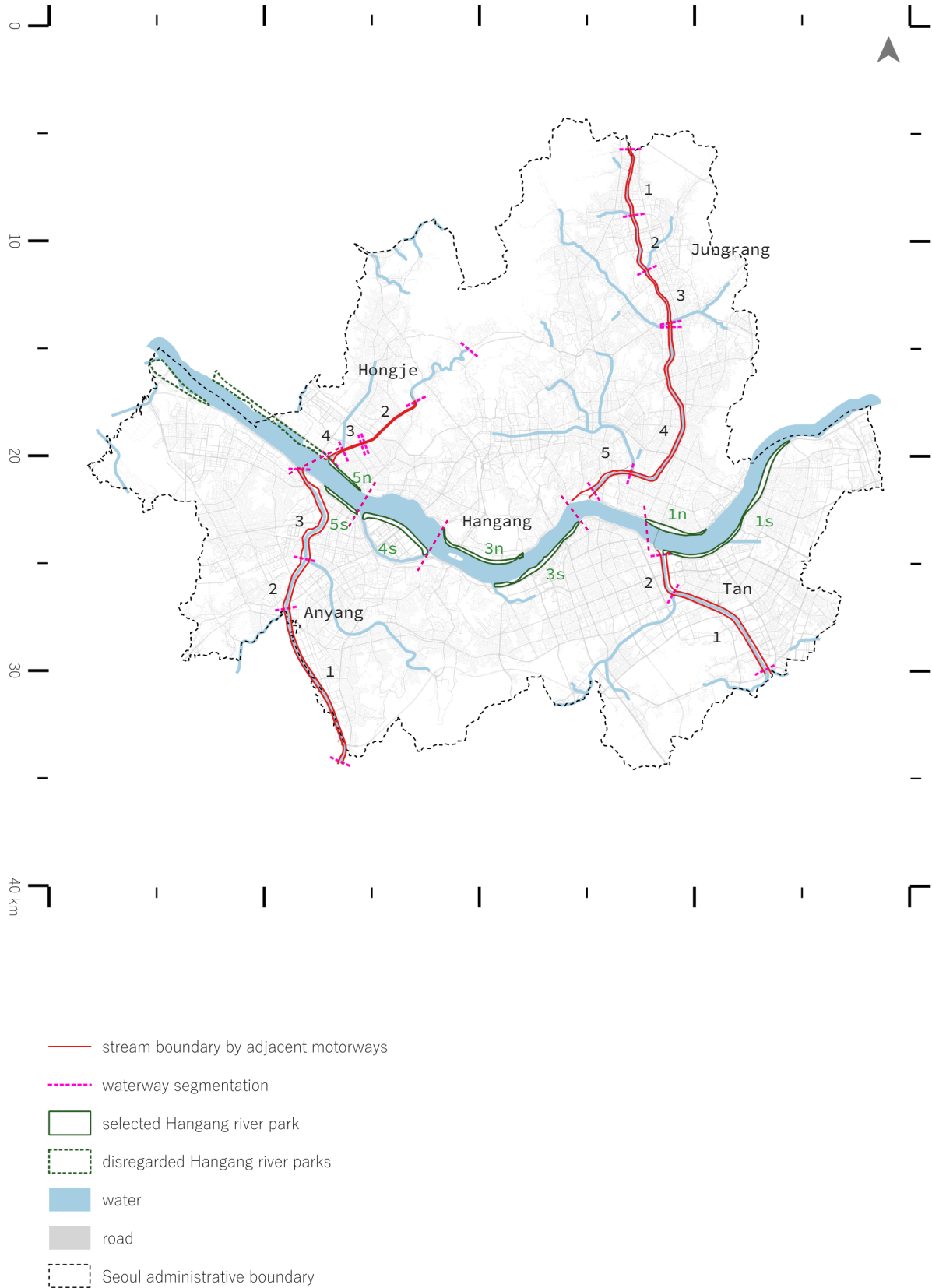


Figure 30 : Typical section and view of selected waterways

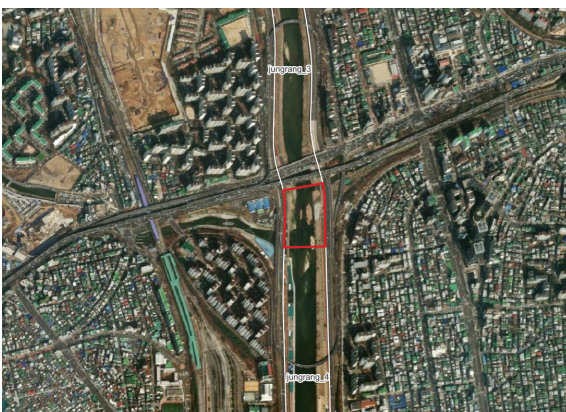
Out of the 4 district streams and Hangang river, 25 waterfront segments were identified according to the methods explained in section 2.4.1, among which 5 were disregarded for analysis due to three reasons (Figure 31). First, the most upstream piece of Hongje stream could not be defined by the outline of adjacent mobility infrastructures. Second, the surrounding environments of the two western Hangang river parks were distinctly suburban. Lastly, the two short segments in Jungrang and Hongje were less than 200m long. Hongje's short segment between 2 and 3 is where the waterfront is not accessible to pedestrians on one side of the stream; in Jungrang's case it is an in-between piece between 3 and 4 where two tributaries join the district stream in proximity. As a result, 20 waterfronts were used for this study (Figure 30).



Upper segment of Hongje stream:  
Not flanked by autoways



Western Hangang river parks:  
In suburban context




In-between segment in Jungrang stream:  
Too short

Figure 31 : Typical section and view of selected waterways

Table 00

Waterfront	Width (m)	Length (m)
Hongje_2	41	3,158
Hongje_3	85.5	904
Hongje_4	111	727
Jungrang_1	121	3,212
Jungrang_2	125.3	2,755
Jungrang_3	123.3	2,759
Jungrang_4	155.5	8,867
Jungrang_5	215.5	2,060
Anyang_1	182.5	7,801
Anyang_2	305.5	2,502
Anyang_3	338	4,897
Tan_1	211.5	5,894
Tan_2	222.5	1,963
Hangang_1n (Ttukseom)	152.06	3,111
Hangang_1s (Jamsil + Gwangnaru)	141.3	8,968.5
Hangang_3n (Ichon)	114.6	4,958
Hangang_3s (Banpo + Jamwon)	147.03	5,251
Hangang_4s (Yeouido)	192.2	3,878
Hangang_5n (Mangwon)	95	2,161
Hangang_5s (Yanghwa)	119.4	2,079

As shown in Table 02, the 20 waterfronts selected for analysis illustrated in Figure00 varied significantly both in width and length. The width of streams was averaged between the most upstream and downstream sections. Their lengths were calculated by the segmented centerlines. Length of Hangang parks were calculated as  $(perimeter/2)$ , simplified into pointed oval shapes (). Accordingly, their widths were calculated as  $(area/length)$ . Naturally, streams were wider as they moved downstream. However, this did not apply to Hangang river, as their urban waterfronts demonstrate similar widths consistently. Hongje was the smallest in size, owing more to the disrupted pedestrian movement within the stream than to natural segmentation.

— Motorway  
— Water  
- - - Waterfront boundary

0 100 200m



Hongje



Jungrang



Anyang



Tan



Hangang river



Figure 32 : Typical section and view of selected waterways

### 3.1.2 Areas of influence

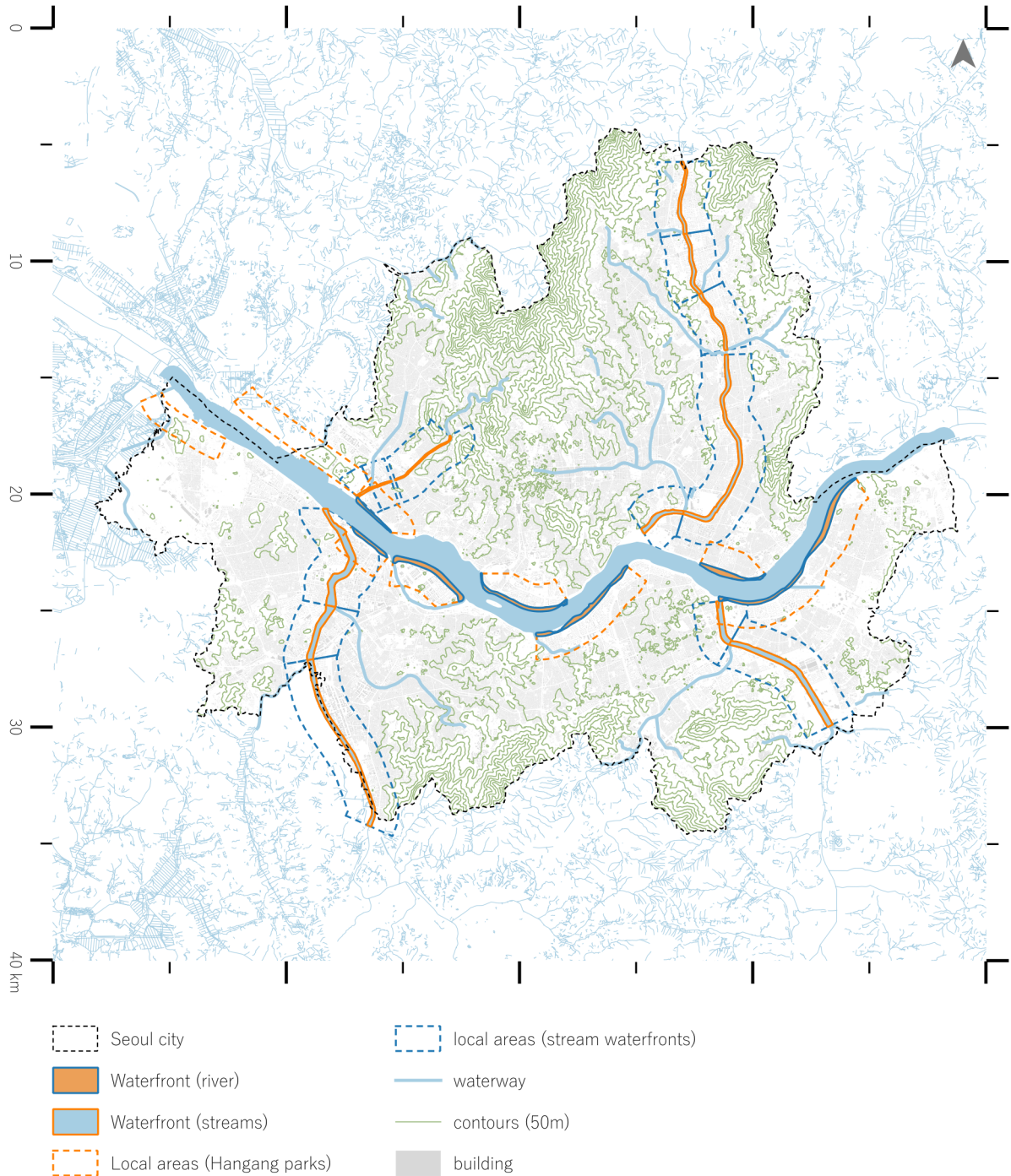


Figure 33 : Locally influenced areas of 20 defined waterfronts

Area of influence in two spatial scales (local and city-wide) were defined according to method discussed in 2.4.1. Figure 33 shows the local area of influence of the 20 waterfronts and Figure 34 gives an example of the city-wide version with Anyang-1 waterfront.

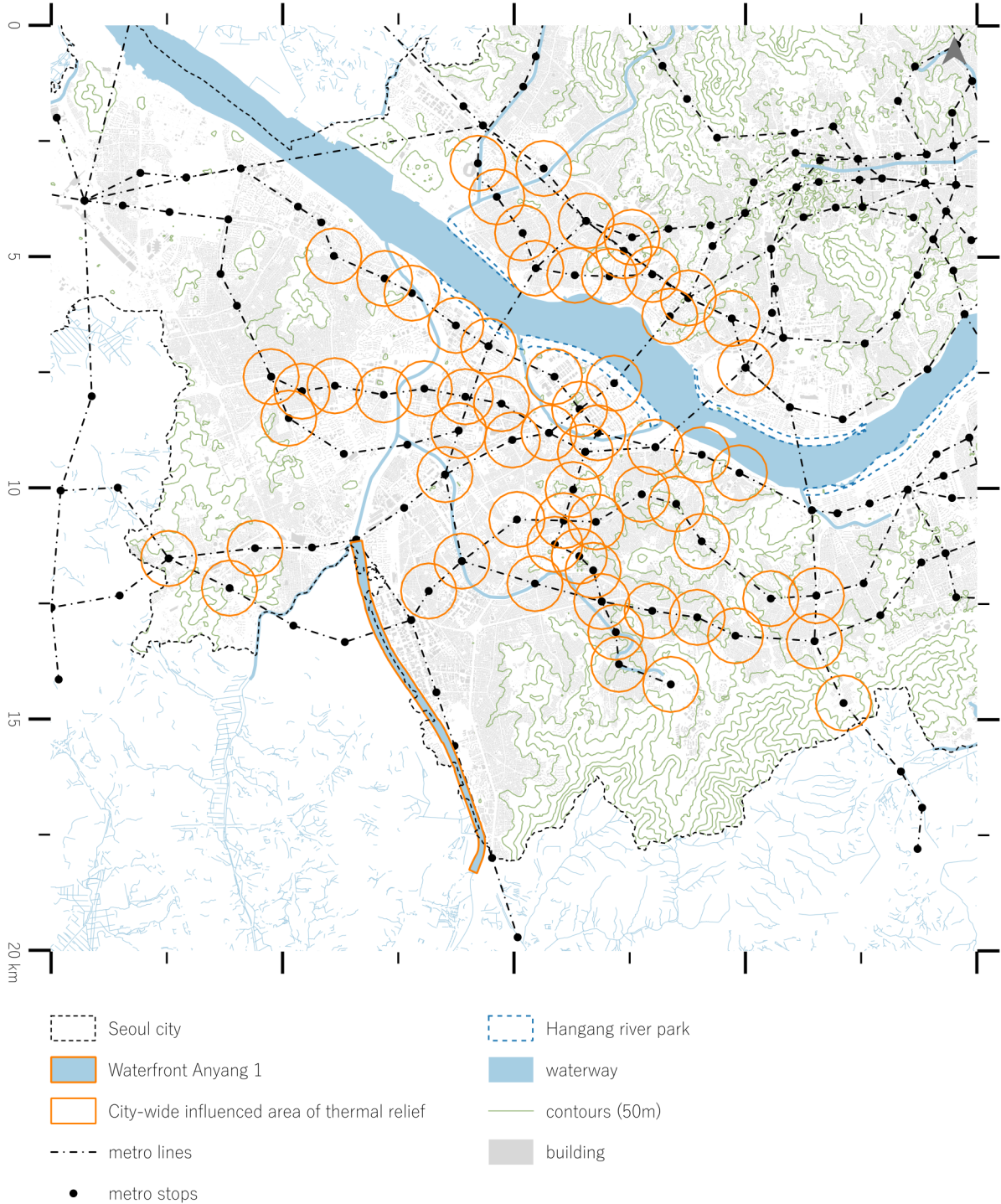


Figure 34 : City-wide influenced areas of waterfront Anyang-1 during heatwaves

### 3.2 Climate adaptivity analysis

The results of the climate adaptivity analysis are presented in three parts. First, variables related to heatwaves and flash floods are presented separately where their basic characteristics and correlations are pointed out. Next, the variables are combined and grouped per waterway to identify unique properties tied to certain waterways.

#### 3.2.1 Performances against heatwaves

Table 03 : Spatial variables related to climate adaptivity against heatwaves

name	(Local_TR)	(City_TR)	(Local_TRA)	(City_TRA)
	local_thermal_relief	city_thermal_relief	local_thermal_refuge_accessibility	city_thermal_refuge_accessibility
anyang_1	0.086	0.139	0.708	0.393
anyang_2	0.106	0.141	0.692	0.299
anyang_3	0.080	0.118	0.684	0.366
hangang_1n	0.153	0.163	0.930	0.522
hangang_1s	0.115	0.154	0.828	0.648
hangang_3n	0.086	0.145	0.632	0.442
hangang_3s	0.114	0.150	0.734	0.332
hangang_4s	0.049	0.144	0.806	0.349
hangang_5n	0.158	0.173	0.905	0.469
hangang_5s	0.124	0.148	0.724	0.352
hongje_2	0.195	0.239	0.654	0.335
hongje_3	0.226	0.241	0.634	0.233
hongje_4	0.155	0.201	0.239	0.000
jungrang_1	0.030	0.090	0.479	0.196
jungrang_2	0.028	0.095	0.526	0.192
jungrang_3	0.032	0.080	0.599	0.308
jungrang_4	0.116	0.134	0.677	0.323
jungrang_5	0.051	0.093	0.561	0.169
tan_1	0.068	0.114	0.612	0.214
tan_2	0.065	0.104	0.652	0.152

Table 03 shows the waterfronts' performances against heat waves. Local and city-wide thermal relief displayed a strong correlation while the local variable was always lower than the city-wide variable (Figure 35). Waterfronts that deviated from this correlation displayed significantly low local thermal relief compared to the city-wide version, such as Anyang 1 and Hangang 4s. This, however, only indicates that these waterfronts' adjacent areas also performed highly in thermal relief, and should not be considered as outliers. On the other hand, thermal refuge accessibility demonstrated a more consistent pattern (Figure 36). Although accessibility of both scales was assessed through identical pedestrian networks, the unique location of waterfront entrances and public transportation nodes of each waterfront resulted in some variations. It should be noted that while the majority of local accessibility exceeded 0.64 (the radius-to-grid ratio), the majority of city-wide accessibility fell under this standard.

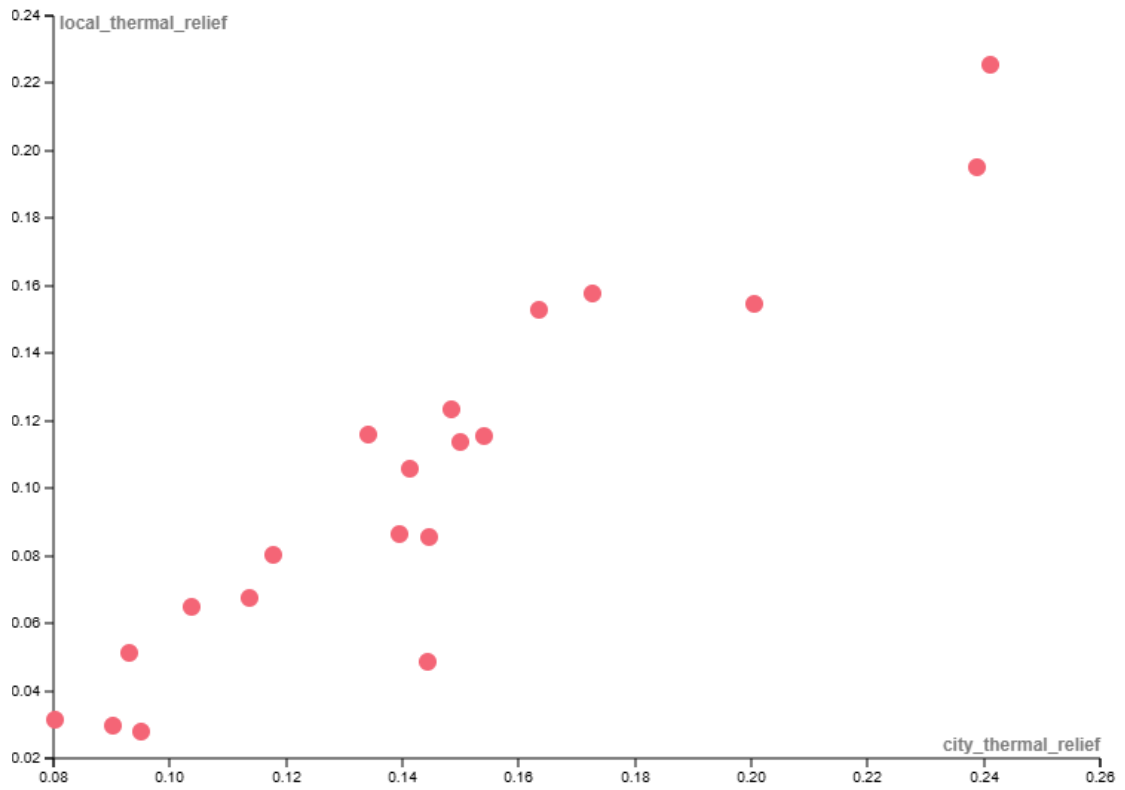


Figure 35 : Correlation between local and city-wide thermal relief

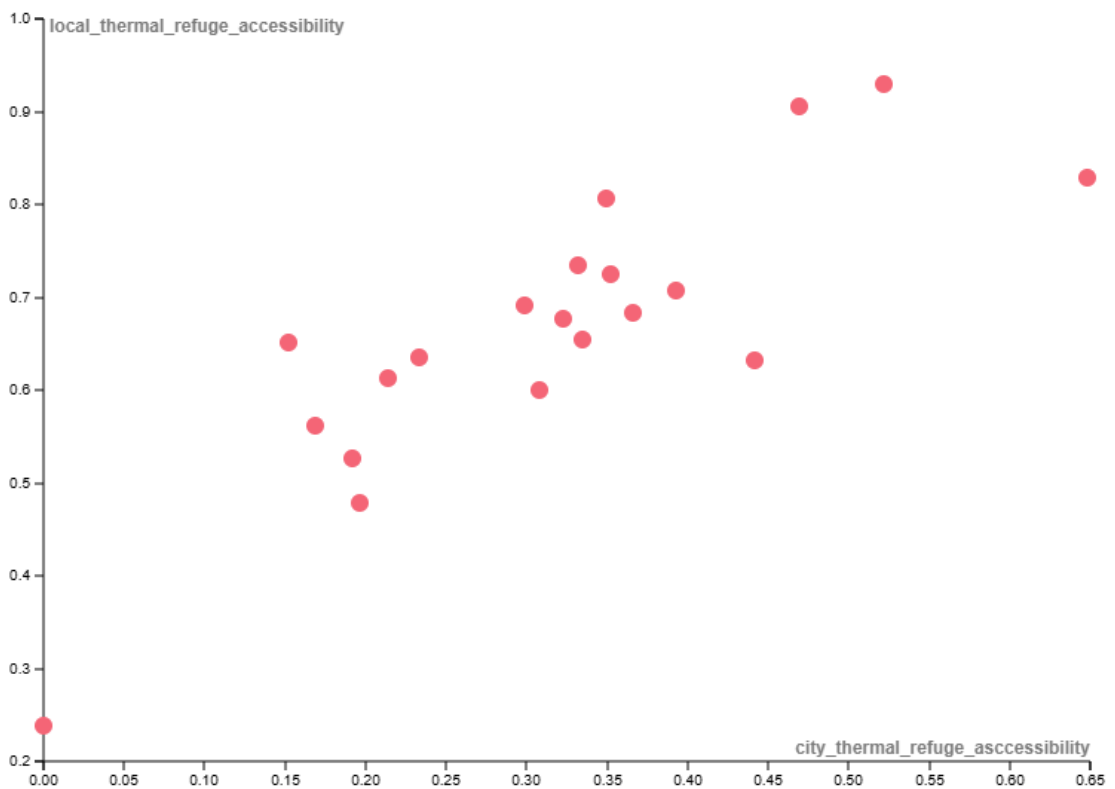


Figure 36 : Correlation between local and city-wide thermal refuge accessibility

### 3.2.2 Performances against flash floods

Table 04 : Spatial variables related to climate adaptivity against flash floods

name	(FBC)	(Local_FMR)	(City_FMR)
	flood_buffer_capacity	local_flooded_mobility_robustness	city_flooded_mobility_robustness
anyang_1	1.000	0.602	0.701
anyang_2	1.000	0.248	0.807
anyang_3	0.754	0.159	0.807
hangang_1n	1.000	0.874	0.528
hangang_1s	1.000	0.889	0.528
hangang_3n	0.993	0.806	0.752
hangang_3s	0.592	0.681	0.752
hangang_4s	0.785	0.451	0.807
hangang_5n	0.902	0.715	0.807
hangang_5s	0.771	0.174	0.807
hongje_2	1.000	0.871	0.627
hongje_3	1.000	0.115	0.807
hongje_4	1.000	0.042	0.807
jungrang_1	1.000	0.994	0.130
jungrang_2	1.000	0.983	0.202
jungrang_3	0.760	0.883	0.701
jungrang_4	0.992	0.917	0.752
jungrang_5	1.000	0.737	0.807
tan_1	1.000	0.219	0.222
tan_2	1.000	0.612	0.241

The flood-related performances show little correlation as shown in Table 04. The buffer capacity displayed a trend that suggests downstream waterfronts are more likely to overflow as water accumulates from upstream. Nevertheless, Jungrang 3 and Hangang 3s showed abrupt change of the variable, most likely due to their drainage area and input from tributary streams. Opposite tendency was observed for the city-wide mobility robustness which showed higher risk for upstream waterfronts due to higher riverbanks. On the contrary, such a pattern was rarely observed in the local index; this variation between the two spatial scales points to the spatial segregation between automobile and pedestrian networks near the waterfronts (Figure 37).

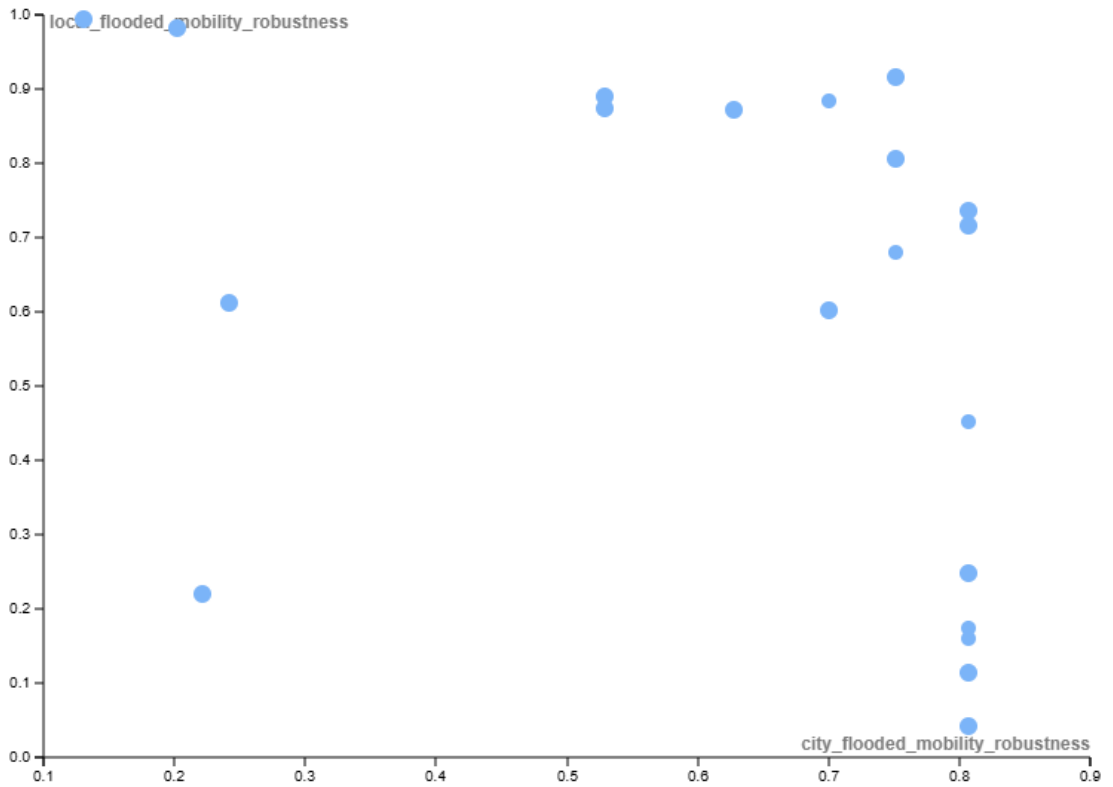


Figure 37 : Correlation between local and city-wide flooded mobility robustness

### 3.2.3 Combined analysis per waterway

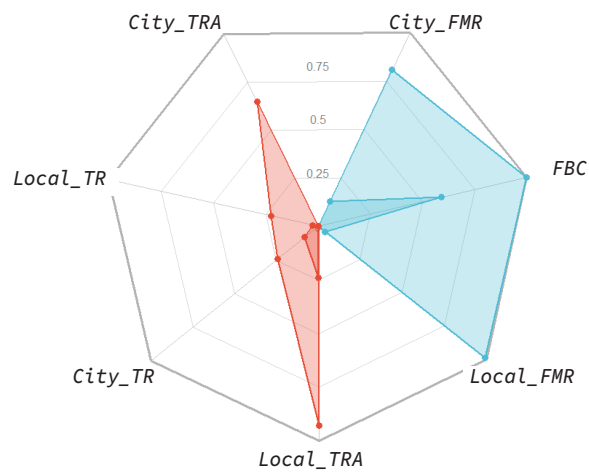


Figure 38 : Range of climate adaptive performances shown in butterfly radar chart

The most notable difference between the two dimensions (flash flood and heat wave) is that while performances against flood fluctuated considerably, those against heat waves only displayed subtle variations, especially thermal relief (Figure 38). This is due to the method of proxying air temperature which limits the distribution of the calculated values. Also, the flood-related variables were simulated outcomes whereas the heat-related variables were results of existing phenomena. Therefore, the different methods applied to derive these variables should be considered when observing the results.

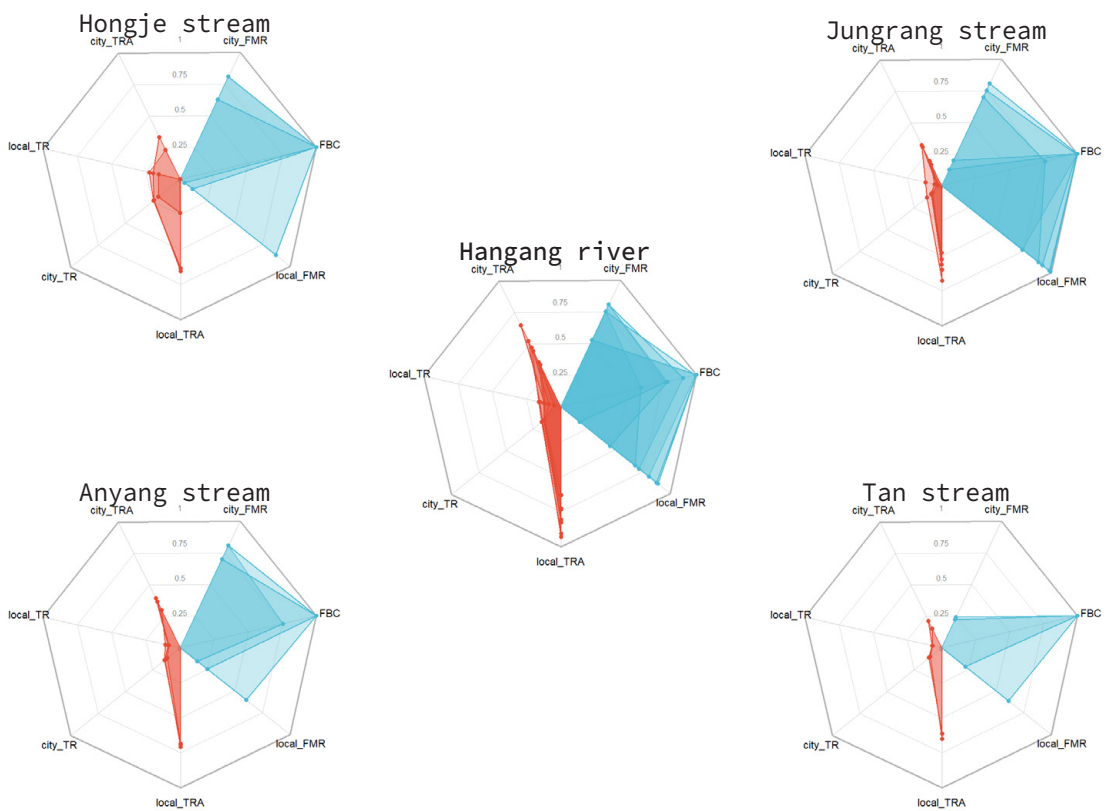


Figure 39 : Overlapped climate adaptive performances of five selected waterways

When comparing the variables grouped by waterways, similar patterns of heat-related performances were observed within the same stream, while flood-related performances exhibited more varied patterns (Figure 39). Hongje and Hangang river displayed better thermal relief than the rest of the waterways, especially the latter also performing better in thermal relief accessibility. Jungrang and Tan performed poorly under heat waves, while showing very low chances of overflowing than other waterfronts. Hangang waterfronts' city-wide flooded mobility robustness was higher overall, even for upstream segments; this is most likely due to their special condition of having the two main motorways as dikes. Overall, Hangang displayed more consistent patterns in both dimensions compared to other waterways, implying higher morphological resemblance along the river.

### 3.3 Waterfront classification

Table 05 : Relative weighing system of seven climate adaptivity variables

	city_TR	city_TRA	local_TR	local_TRA	FBC	city_FMR	local_FMR	sum	Weight
city_TR		1	1	1	1	1	1	6	12
city_TRA	0		0	0	0	1	0	1	2
local_TR	0	1		1	1	1	1	5	10
local_TRA	0	1	0		0	1	1	3	6
FBC	0	1	0	0		1	1	3	6
city_FMC	0	0	0	0	0		0	0.5	1
local_FMC	0	1	0	0	0	1		2	4

The original variables were weighed relatively to compensate for the subtle differences displayed in heat wave related variables. This was done to prevent the highly fluctuating flood variables from overpowering the heat-related ones. The relative weights were determined by comparing each variable's priority over another and giving them binary scores. These scores were then added for each variable; if 0 existed, it was incremented to 0.5 and all weights were multiplied by 2. In this study, the relative weights were determined based on the frequency and the number of physically affected people<sup>8</sup>. For network-related properties, local scale was assumed to be of more importance. These priorities yielded results shown in Table 05.

As a result, 20 waterfronts were qualitatively classified into 4 types that displayed a varied mix of different waterways and upstream/downstream locations. Hangang and Jungrang tended to cluster, but independent of geographical locations. Other waterways were more evenly distributed in different types (Figure 41). This indicates that the influence of morphological and geographical properties was balanced in the weighing system. While a classification based on the original variables would have yielded results centered on geo-spatial qualities where the grouping of waterfronts would display geographic patterns<sup>9</sup>, this weighted version reflects the perceived impact of such on daily life, which led to evenly distributed results (Figure 40).

8 During the last 20 years, total number of days with more than 50mm rainfall was 146 whereas days of heatwaves was 262 (KMA Weather Data Service, 2026). Number of injured or dead people was 17 for floods (Seoul Open Data Plaza, 2026) and 883 for heatwaves (Public Data Portal, 2025).

9 For qualitative classification based on original variables, see Appendix B and C

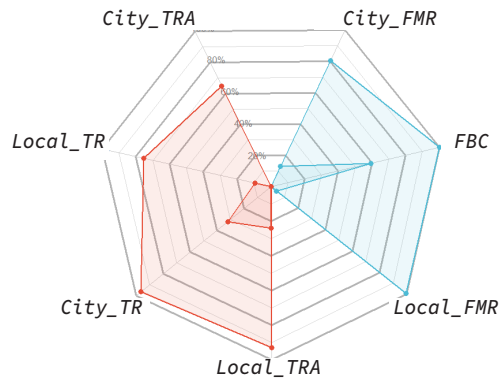
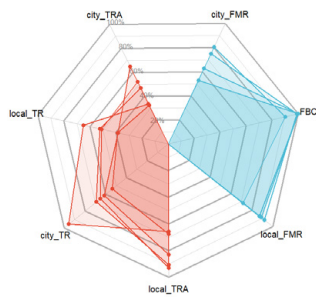


Figure 40 : Range of weighted climate adaptive performances shown in butterfly radar chart

Type 1 displayed high performance under both flash floods and heatwaves. For this type, only the improvement of city-wide thermal refuge accessibility is the central issue. Flooded mobility robustness may also need to be addressed in some cases, but with less priority than thermal issues. Type 2 consists of waterfronts that show adequate performances against floods but perform poorly during heatwaves. Although they are less likely to overflow, they will cause severe damage if it does occur compared to Type 1. Thermal relief and thermal refuge accessibility was lowest in this group. Type 3 displays imbalance between thermal relief and accessibility in city-scale, and exhibits serious disruption in pedestrian networks if flooded. Some of them have lower flood buffer capacity which indicates for them possibility of flash floods. Type 4 is a mixture of Type 2 and 3, with low thermal performances and higher possibility of flash floods with considerable disruption on mobility networks of both scales.

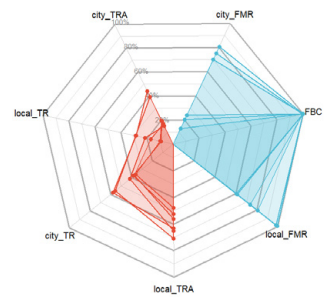
**Type #1**

Flood-safe  
&  
High thermal  
performance



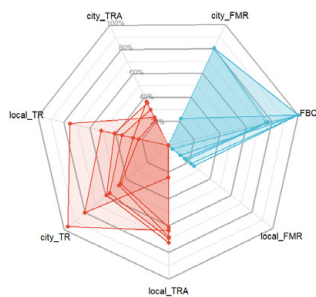
**Type #2**

Flood-safe  
&  
Low thermal  
performance



**Type #3**

Vulnerable  
pedestrian  
network  
if flooded



**Type #4**

Likely to  
flood  
&  
Low  
thermal  
performance

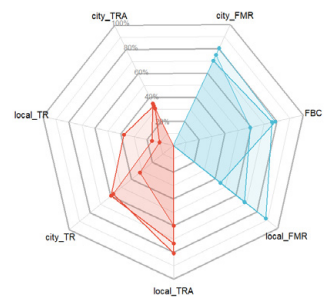


Figure 41 : Five waterfront types as result of qualitative classification of weighted variables

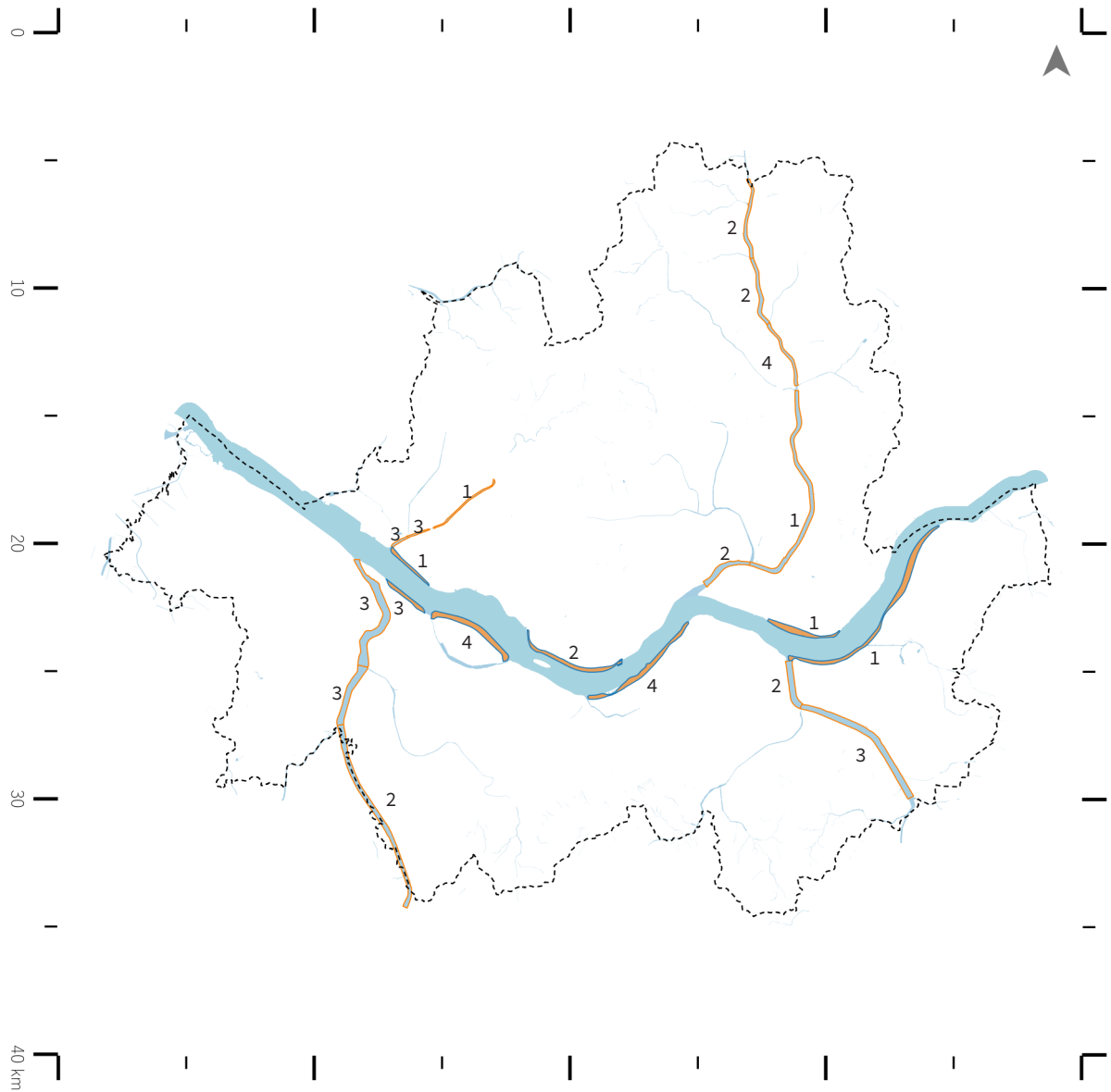


Figure 42 : Geographical distribution of five waterfront types

- 1: Flood-safe & High thermal performance
- 2: Flood-safe & Low thermal performance
- 3: Vulnerable pedestrian network if flooded
- 4: Likely to flood & Low thermal performance

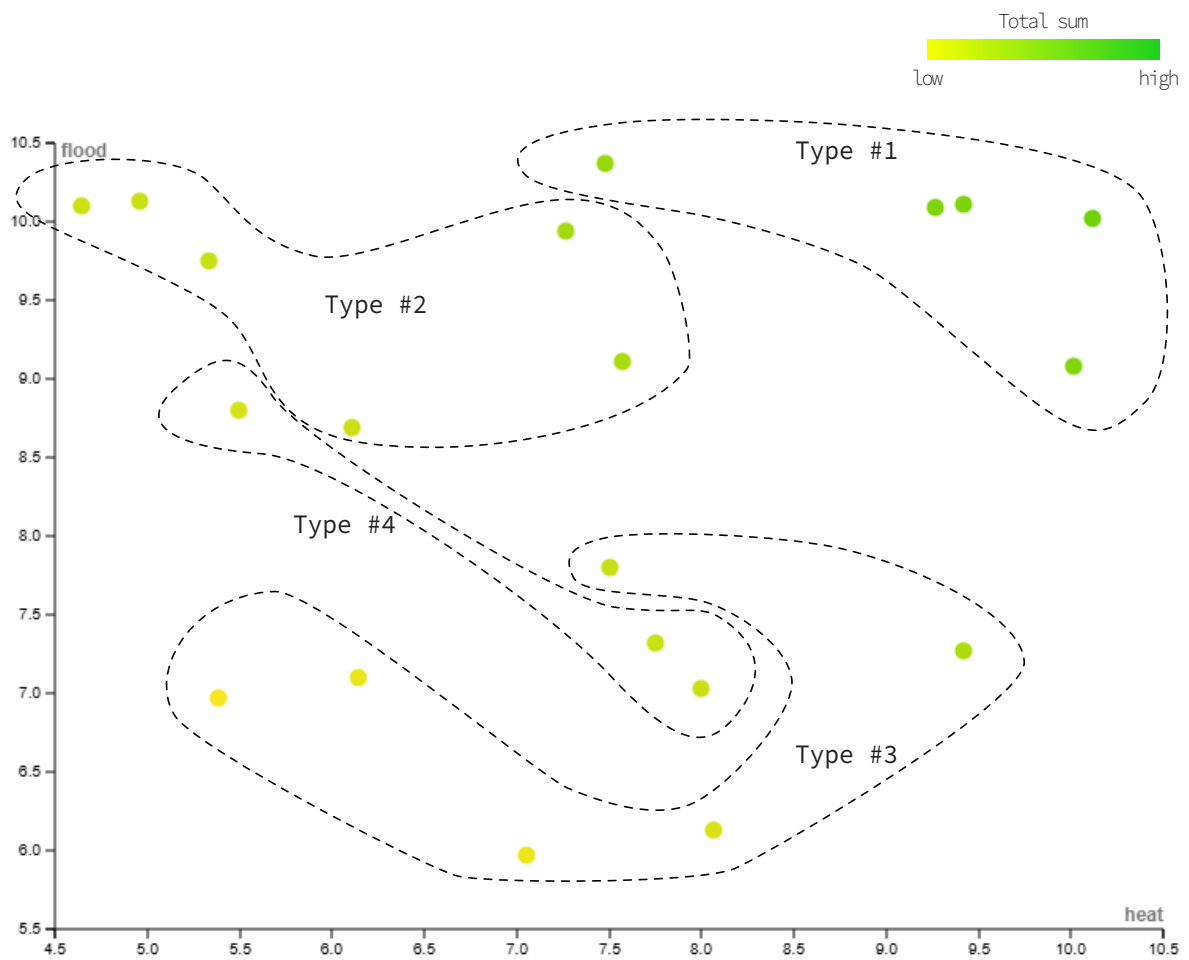


Figure 43 : Scatterplot of waterfron types by comprehensive performances against heatwaves and flash floods

Figure 42 shows the geographical distribution of the qualitative types. Except for Type 4 which displayed higher possibility of overflow, thus logically more likely for downstream waterfron types, types tended to be distributed evenly throughout Seoul. Figure 43 illustrates the distribution of the types in terms of weighted performances. Each axis represents the collective sum of climate adaptivity variables shown in Table 03 and 04 multiplied by relative weights shown in Table 05. Because the types were defined qualitatively, their distribution inside quantitative graph appears somewhat unnatural.

### 3.4 Design principles

The purpose of design principles is to provide direction and structure to the design section of the framework. In other words, they clarify the objectives under which the analysis results will be operationalized. The design principles in this study aim to 1) incorporate daily life trajectories under moderate climate conditions, and 2) to increase feasibility through governmental involvement.

#### Adaptive Everyday Network

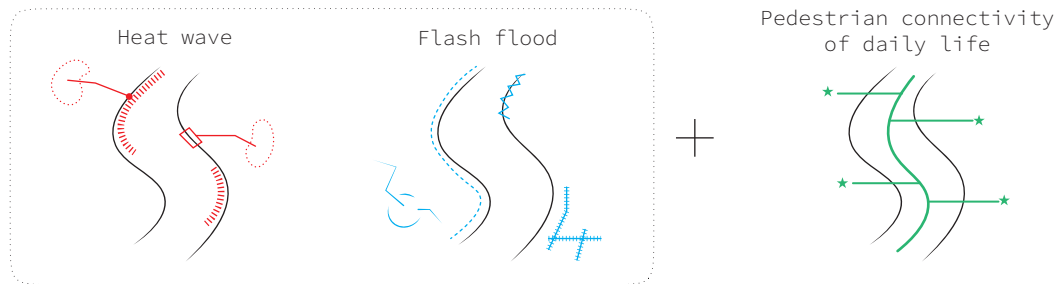


Figure 44 : Diagram of first design principle - Adaptive Everyday Network

While the analysis section of this study investigates the impact of open space on daily life under extreme climatic conditions, climate adaptive design derived from it should not be limited to improving certain performances during specific events. Rather, they should contribute to the improvement of some quality of daily life during moderate climates, which outnumber the days of heat waves or flash floods throughout the year. Therefore, a third layer of pedestrian connectivity is overlaid (Figure 44). This specific aspect, which is closely related to the network-related section of the analysis, increases the potential to expand the role of waterfronts to become the spine of a slow mobility network. In conclusion, the outcome should be multi-functional open space designs that contribute to improvement of daily life during moderate climate as well as during extreme summer events.

#### Public Stitchwork

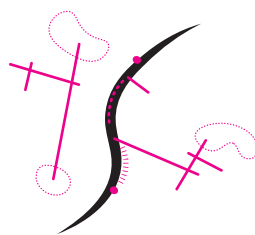


Figure 45 : Diagram of second design principle - Public Stitchwork

The need for a distinct approach of design for governmental bodies originates from clear distinctions between public and private space in Korea. As demonstrated by the conflicts regarding the public passages created inside private plots (Jung, 2026), involvement of privately owned open spaces in public interventions significantly lowers the feasibility of a project. This is why the framework focuses on open spaces already owned and maintained by the state: waterfronts, streets, parks, and public plazas (Figure 45). Private plots that are considered in the framework were limited to small sites that have little appeal to private development: old factories in residential areas, small recycling junk yards, or small buildings with low real estate value. Land expropriation of this form is familiar to city hall who has purchased plots of various land use<sup>19</sup>.

### 3.5 Design process

The design section of the framework provides a set of methods to synthesize the principles with analysis results and translate them into spatial interventions. It consists of four steps: 1) identification of effective intervention locations, 2) selection of design elements, 3) spatialization and interconnection of these elements, and 4) evaluation and selection of optimal design (Figure 46). The analysis results are explicitly relevant in the first two steps which provide the design toolkit and locations. The third step then generates possible spatialization of these elements through topological devices. Stakeholders are involved from this step, whose evaluation criteria build conversation with design iterations to produce multiple design alternatives. The last step consists of methods that guide stakeholders to prioritize certain criteria and decide the most optimal design based on them. Together, the proposed framework shows how the analysis, combined with a set of principles, can produce site-specific spatial strategies from which stakeholders can choose and further develop.

#### Proposed design process

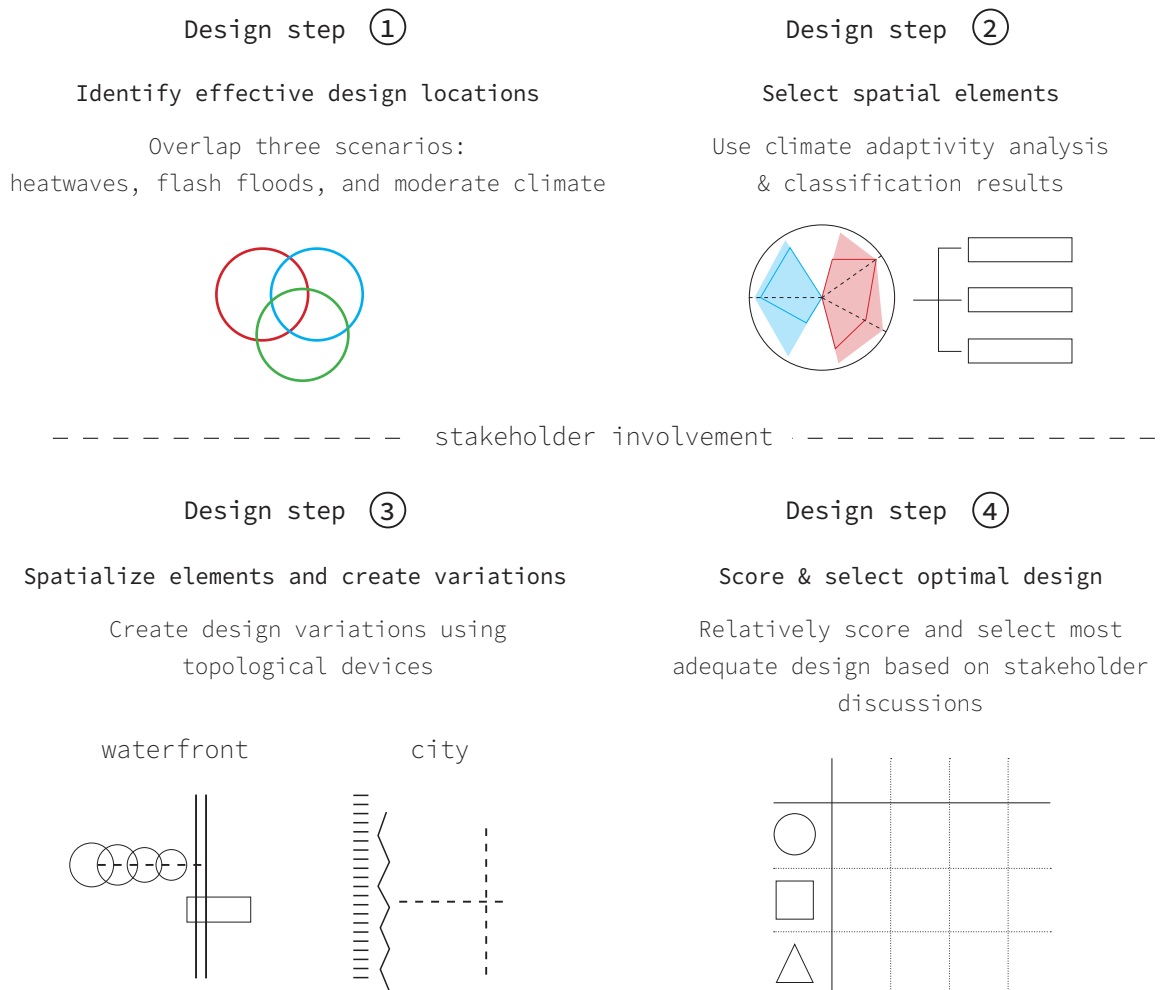


Figure 46 : Design process diagram

10 Although statistics on Seoul's land expropriation (Seoul City Hall, 2026) does not provide data on plot size, the name of the projects imply not only big plots have been object to expropriation during the last 10 years.

### 3.5.1 Design step 1: Identification of effective design locations

The design process begins with overlaying three maps where each map elaborates on the morphological properties relevant to the three scenarios stated in the design principles: heat wave, flash flood, and moderate climate. While the former two maps present combined results of the variables investigated in the climate adaptivity analysis, the third map overlays point of interest (POI), public spaces and blue/green networks. For each map, the locations that require design interventions are outlined and overlapped together to determine the most effective locations (Figure 47).

First, sites that require climate adaptive design interventions are identified in the first two maps. From the heat wave map, “hot spots” and “cooler spots” outside the accessibility isochrones, their potential routes to the waterfront, necessary new entrances, and spaces inside the waterfront that can be used to improve thermal relief are pinpointed. In the flash flood map, inundated paths and potential wadi locations either inside or outside the waterfront are identified. In the last map, possible pedestrian connections between POIs, with the objective of creating human-scale routes behind the car-centric wide roads are drawn. Next, the three “conclusion maps” are laid on top of each other to identify where they overlap geographically. These locations indicate the most effective places for the government to implement a spatial solution; places where maximum benefits can be yielded from minimum input.

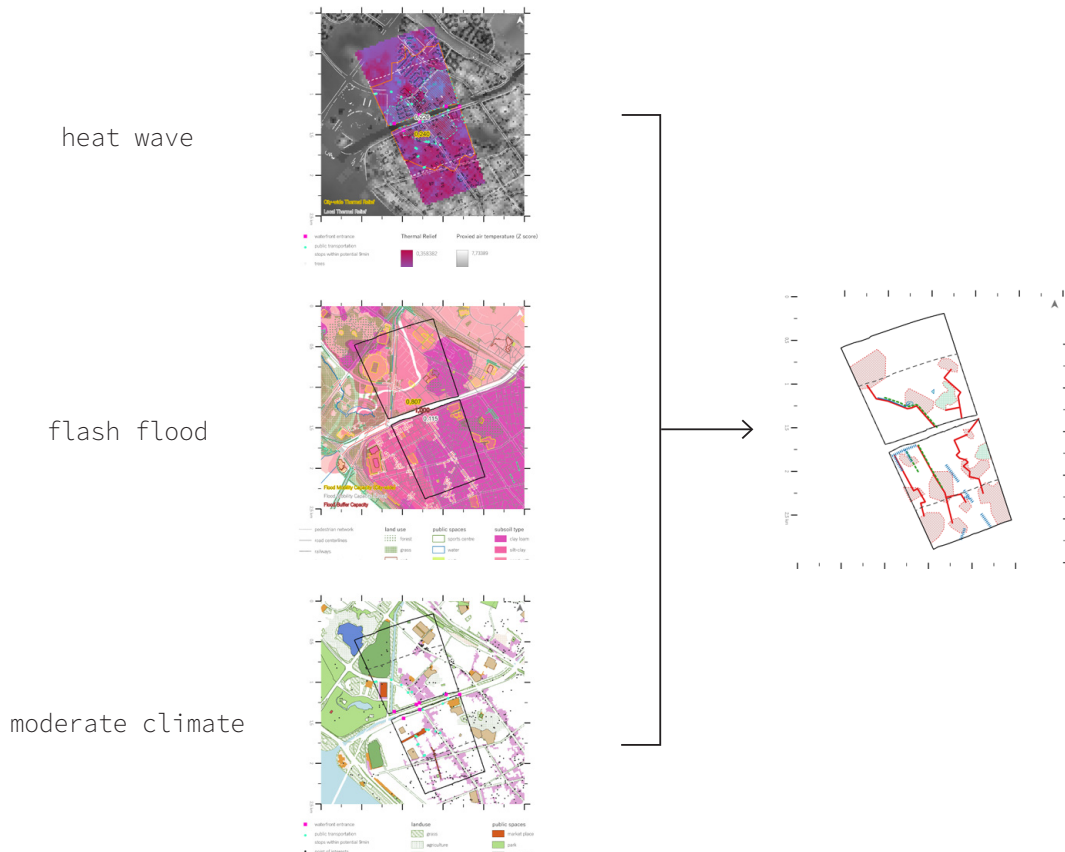


Figure 47 : Identification of effective intervention locations

### 3.5.2 Design step 2: Selection of spatial elements

The second process of the design process delivers a set of possible spatial elements that can be leveraged for a chosen waterfront. Because the classification results from section 3.3 clearly indicate which performance should be improved for each type (Figure 48), they effectively narrow down the spectrum of spatial elements required to address them (Figure 49). These elements are closely related to the morphological properties that were used to calculate the climate adaptivity variables in section 3.2<sup>11</sup>.

#### Target performances

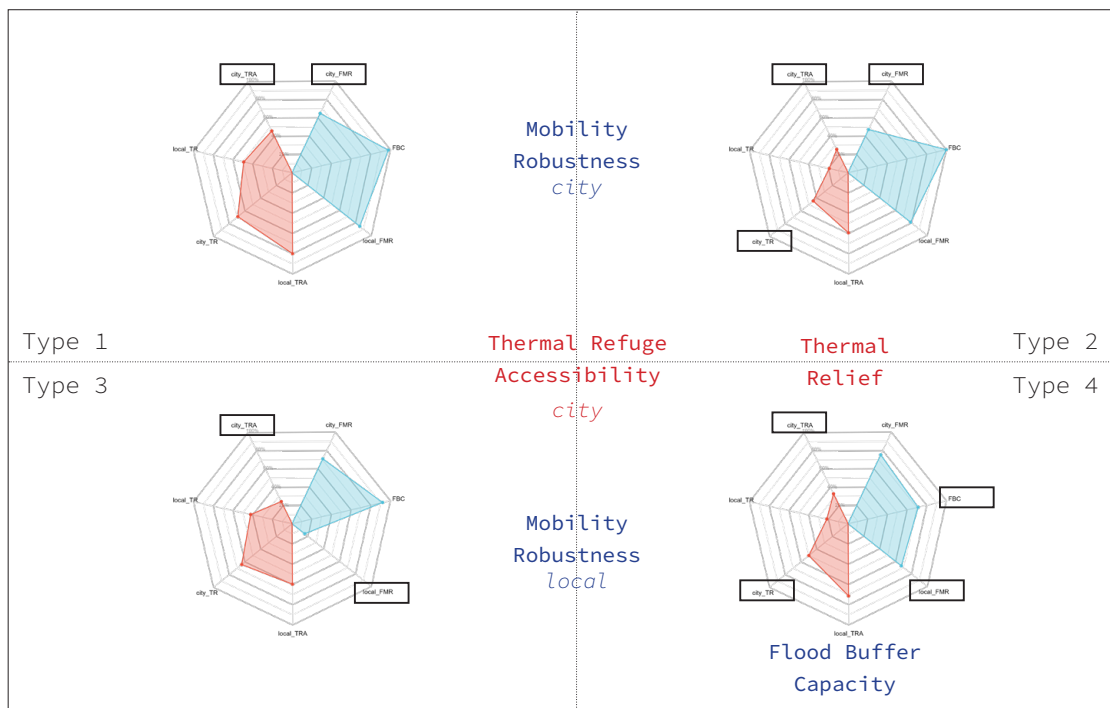


Figure 48 : Climate adaptive performances in need of improvement by waterfront type (radar represents average weighted performances)

#### Spatial elements

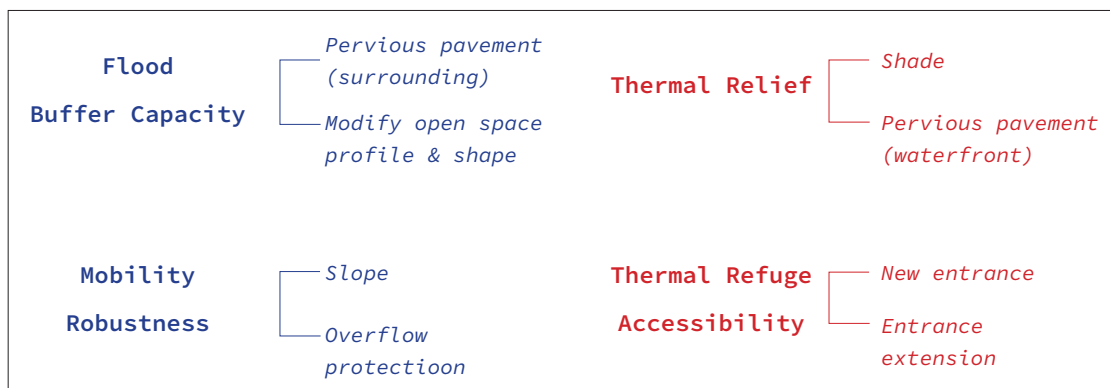


Figure 49 : Spatial elements relevant to each climate adaptive performance

### 3.5.3 Design step 3: Spatialization of elements and creation of variations

The third part of the design framework produces site-specific design alternatives in and around the waterfront by use of topological devices (Figure 50). These devices provide different options as to how the spatial elements selected in the previous step, either separately or combined, can be realized in a site. Due to the distinct spatial conditions inside and outside the waterfronts, the topological device is differentiated in two versions.

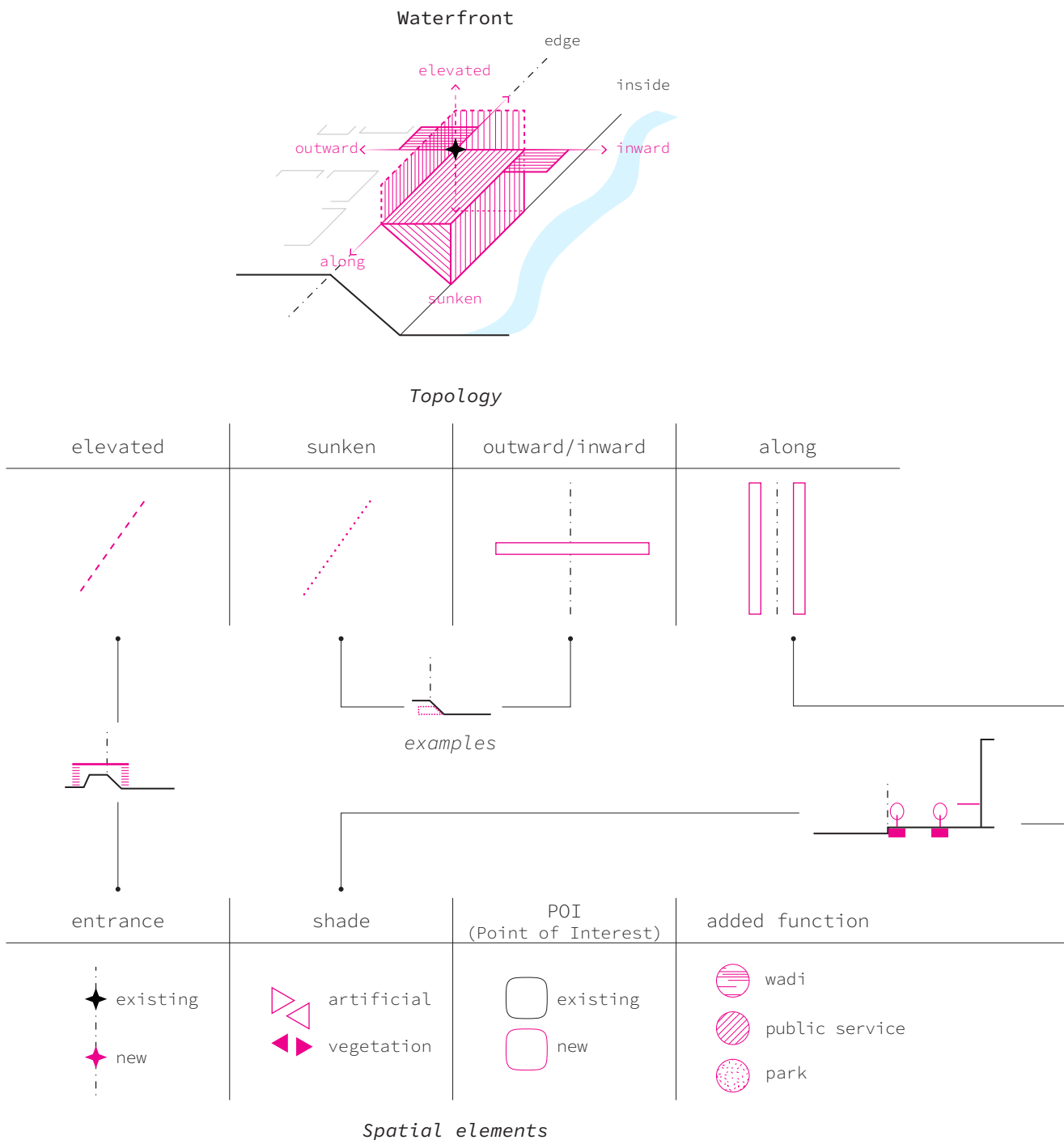
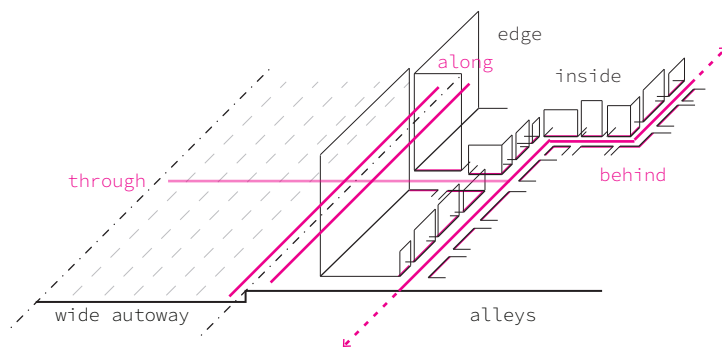


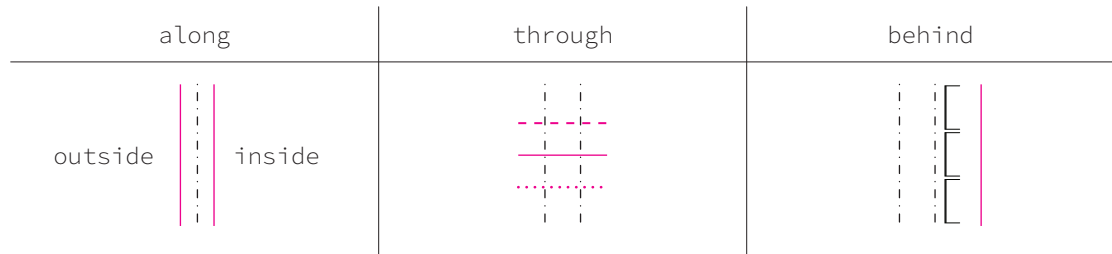
Figure 50 : Two topological devices for spatialization and interconnection

The waterfront version is for interventions that are applied inside or on the edge of the waterfronts, whereas the city version is targeted for open spaces that are irrelevant to the sunken profiles of the waterfronts. Both tools distinguish 'edge' and 'inside' of pedestrian-friendly areas in each context, which provides key to interconnection between the two sites. The purpose of these tools is to help designers generate different variations of climate adaptive strategies that will instigate and enrich discussions between stakeholders.

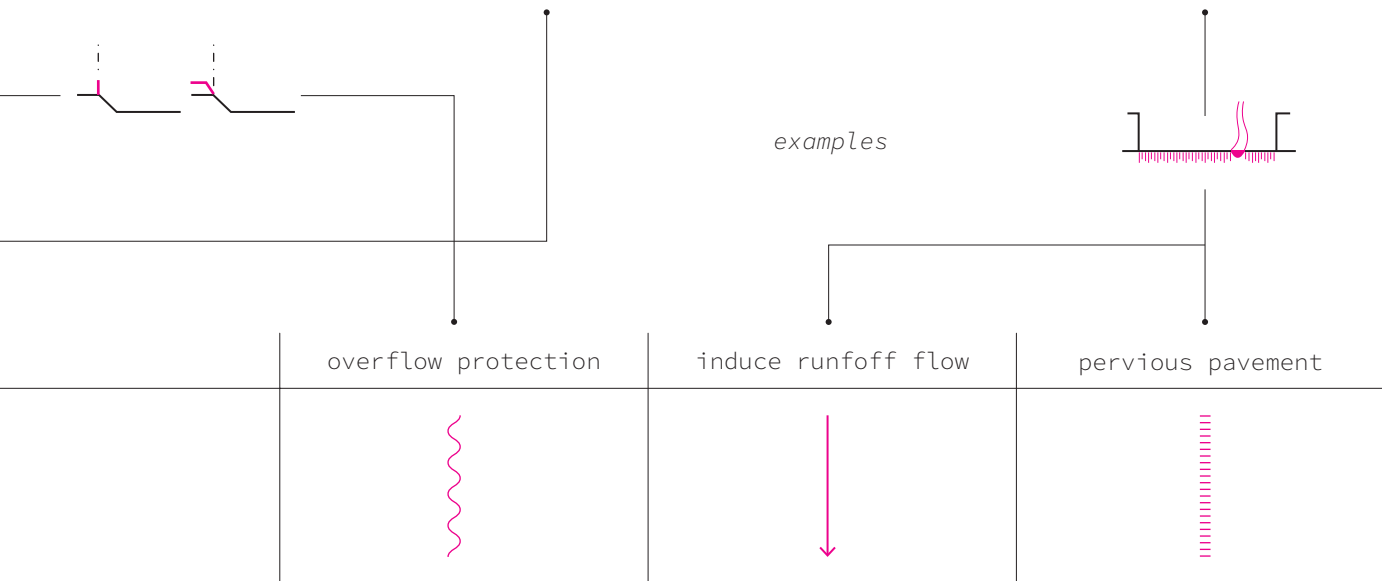
### City



### Topology



### examples



### Spatial elements

### 3.5.4 Design step 4: Evaluation and selection of optimal design

The last phase of the design framework consists of a series of steps that help stakeholders evaluate the design alternatives created in the former step and determine the most optimal strategy.

First, stakeholders discuss and agree on various evaluation criteria other than the climate adaptivity and pedestrian connectivity. Such criteria can be quantitative -for example construction costs or period, number of affected populations, or economic benefit of reducing damage induced by extreme climates- but can also include soft values such as walkability, coherence with existing built environment, or even social integration. This process can either occur after the design iterations or simultaneously; what is critical is that the design alternatives and the discussion of criteria build on each other and result in several distinct spatial strategies as the design criteria become finalized. Then, the stakeholders -including designers- score each option for every criterion relatively. Relative rating signifies that if there were 10 design alternatives, the best performing option would score 10 while the worst would be rated as 1. Lastly, the stakeholders settle on the priority of the criteria for the given site that assigns relative weight to each criterion. The final and comprehensive evaluation is carried out by multiplying the relative scores with their corresponding weights. Finally, the most optimal strategy is identified with the highest score.

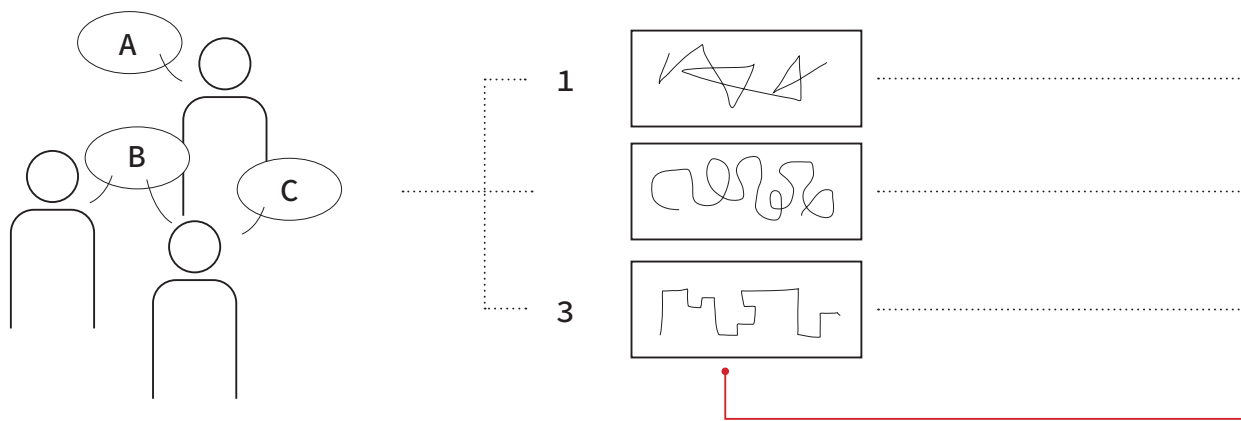
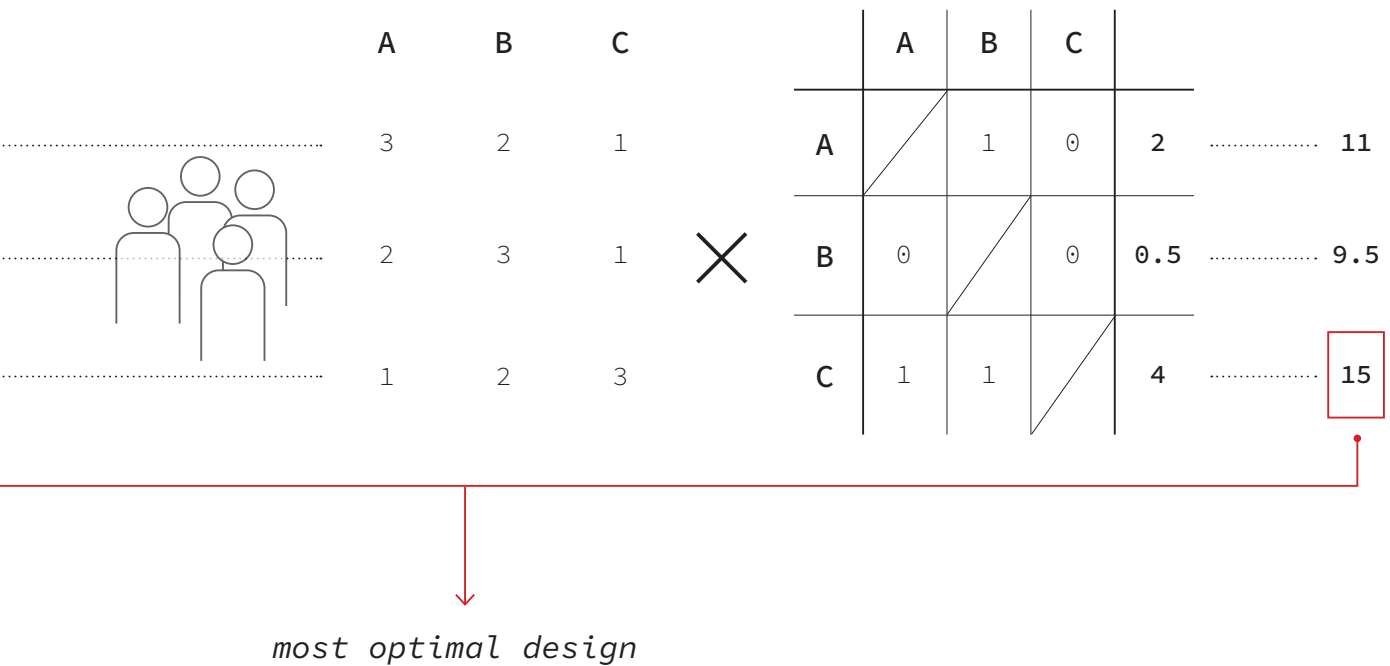


Figure 51 : Evaluation and selection process diagram

This method of relative rating is in line with how design strategies are chosen in the real world; by comparing possible alternatives and using them to determine priorities. Conceptually, it is equivalent to the normalization of scores and weighing them with corresponding coefficients.



### 3.6 Implementation of developed design process in real sites

Three waterfronts with distinct morphological characteristics were chosen to demonstrate how the design process explained in the previous section can be implemented in real sites. A mid-stream segment from Jungrang, downstream waterfront from Hongje, and upstream parks of Hangang river were chosen (Figure 52). They each belong to different waterfront types (Figure 53) and have distinct morphological features (Figure 54). The last step of the design process explained in section 3.5.4 is only demonstrated in the first case of Jungrang. For this waterfront, examples of evaluation from hypothetical stakeholders are given. The other two waterfronts are provided with design alternatives without such hypothetical evaluations.

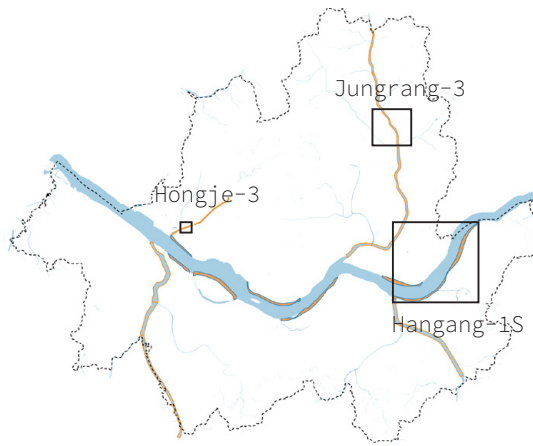


Figure 52 : Location of three selected waterfronts for design implementations

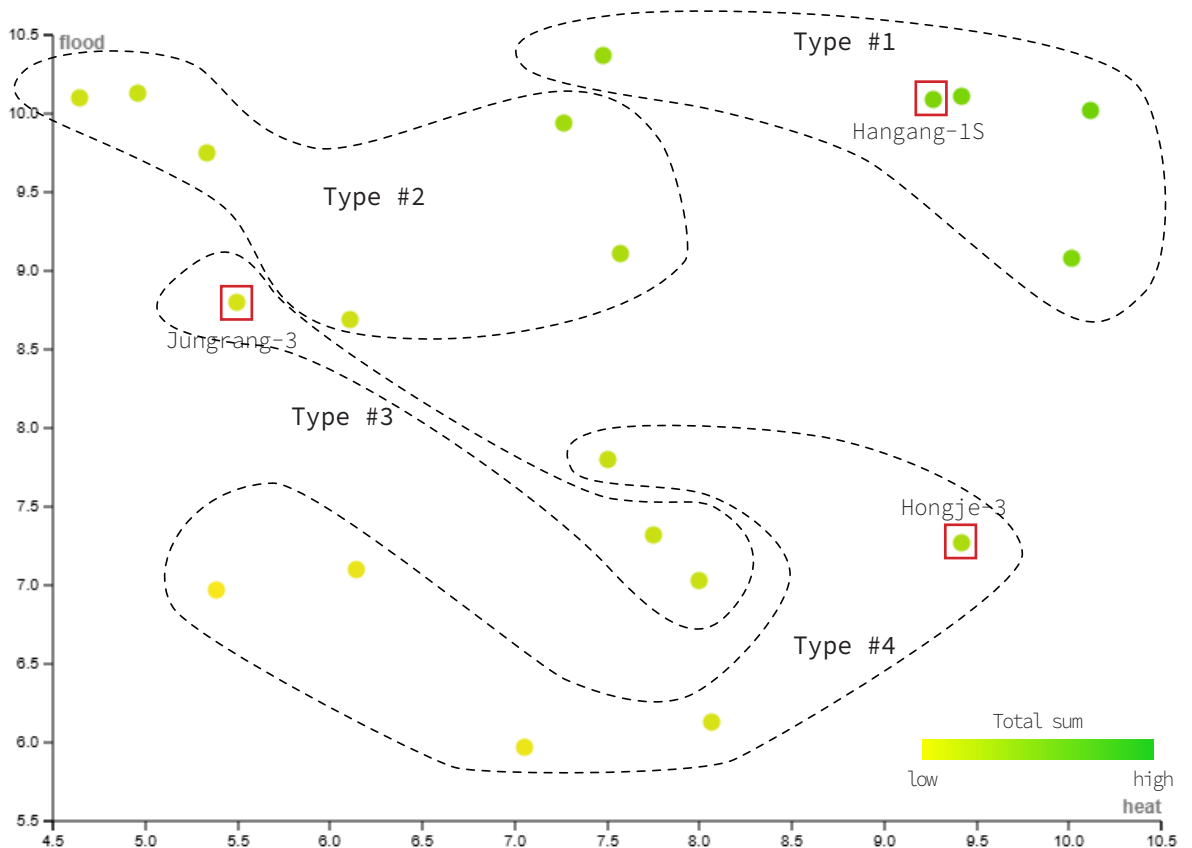


Figure 53 : Distribution of three selected waterfronts in climate adaptivity scatterplot



Jungrang-3



Hongje-3



Hangang-1S

Figure 54 : Typical spatial configuratoin of three waterfronts

### 3.6.1 Implementation of developed design process in Jungrang-3

Table 00 :

<b>Location</b>	North-east of Seoul, mid-stream
<b>Size</b>	123.3m width X 2,759m length
<b>Climate adaptivity</b>	Type 4 Likely to overflow & Low-moderate thermal performance
<b>Spatial conditions</b>	Enclosed by two roads: one motorway and one primary road

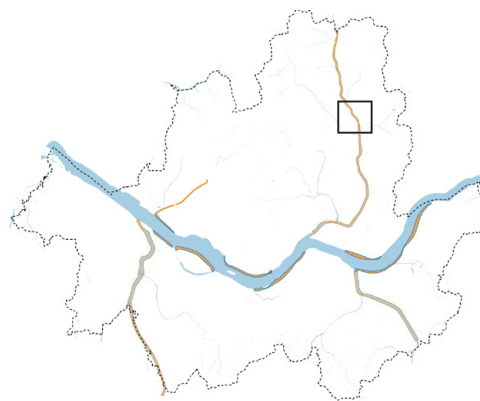


Figure 55 : Location of waterfront Jungrang-3

Jungrang 3 is located in the southernmost part of the Nowon district which was developed in the 1980s as a new town densely built with high-rise apartments. The transition between two distinct urban fabrics -the apartment complexes and low-rise residential houses- begins at the southeast corner of this waterfront. The construction of East Arterial Motorways, which enclose the stream from each side, followed the development of the new town. These motorways were built on the inner slope of the riverbank, despite the obvious exposure to overflowing. This unique spatial condition resulted in high proximity between the waterfront and motorways that is unseen in other streams inside Seoul. As one walks by the water, they are provided with panoramic views of the surrounding area, often with mobility infrastructure on the foreground.



Figure 56 : Waterfront and local area boundaries of Jungrang-3



Figure 57 : Birdseyeview of waterfront Jungrang-3 and its local area



Figure 58 : Relationships with adjacent infrastructures in Jungrang stream

① Identify effective design locations : Jungrang-3

Overlap three scenarios: heatwaves, flash floods, and moderate climate

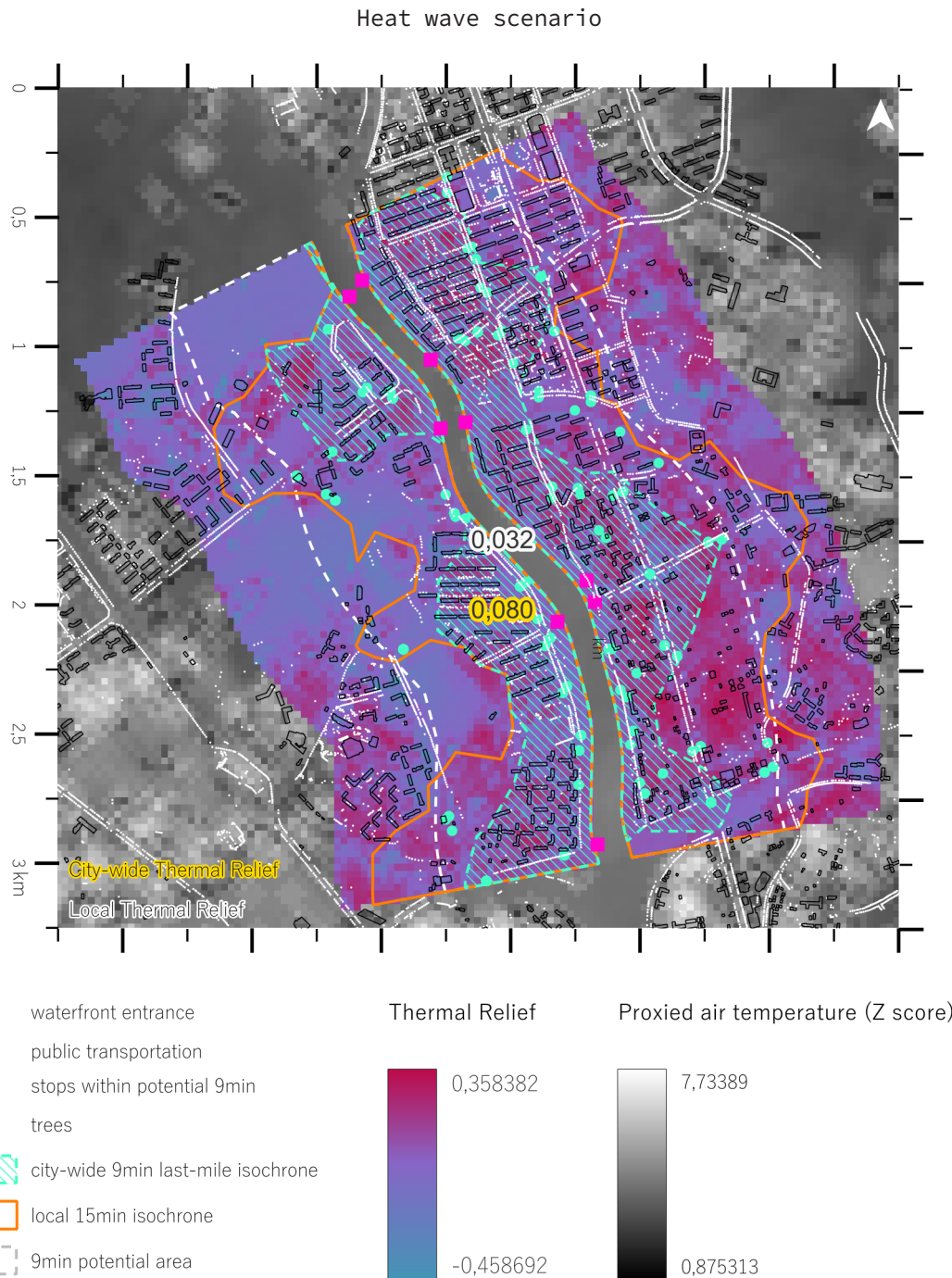


Figure 59 : Analysis of Jungrang-3's climate adaptive performances against heatwaves

Thermal relief in both scales was poor in Jungrang 3, especially in local scale. This trend was noticeable in the whole of Jungrang stream. On the other hand, local thermal refuge accessibility was slightly below the standard, which indicates adequate pedestrian network connected to the waterfront which fails to provide sanctuary from heatwaves. Besides the blind spot spotted on the west in city-wide accessibility, the thermal comfort of the journey to the waterfronts should be also improved, especially on the south-eastern part of the local area.

### Flash flood scenario

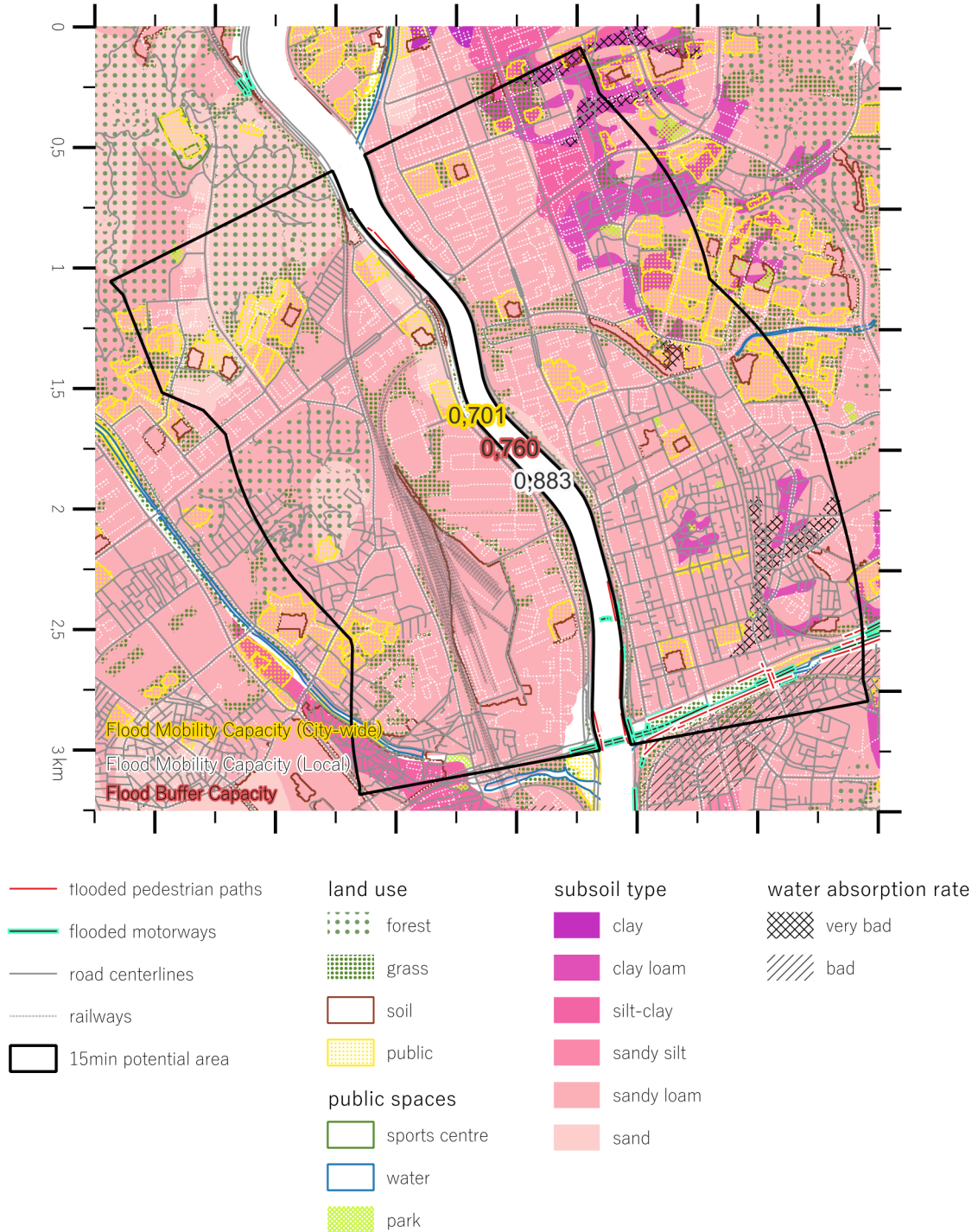


Figure 60 : Analysis of Jungrang-3's climate adaptive performances against flash floods

Although flood buffer capacity indicated higher chance of overflow compared to other waterfronts, the disruption on mobility networks was not so high. The paths that become flooded were all next to tributary streams in the south. However, public open spaces were scarce in the whole local area which points to difficulty of implementing nature-based solutions.

Moderate climate

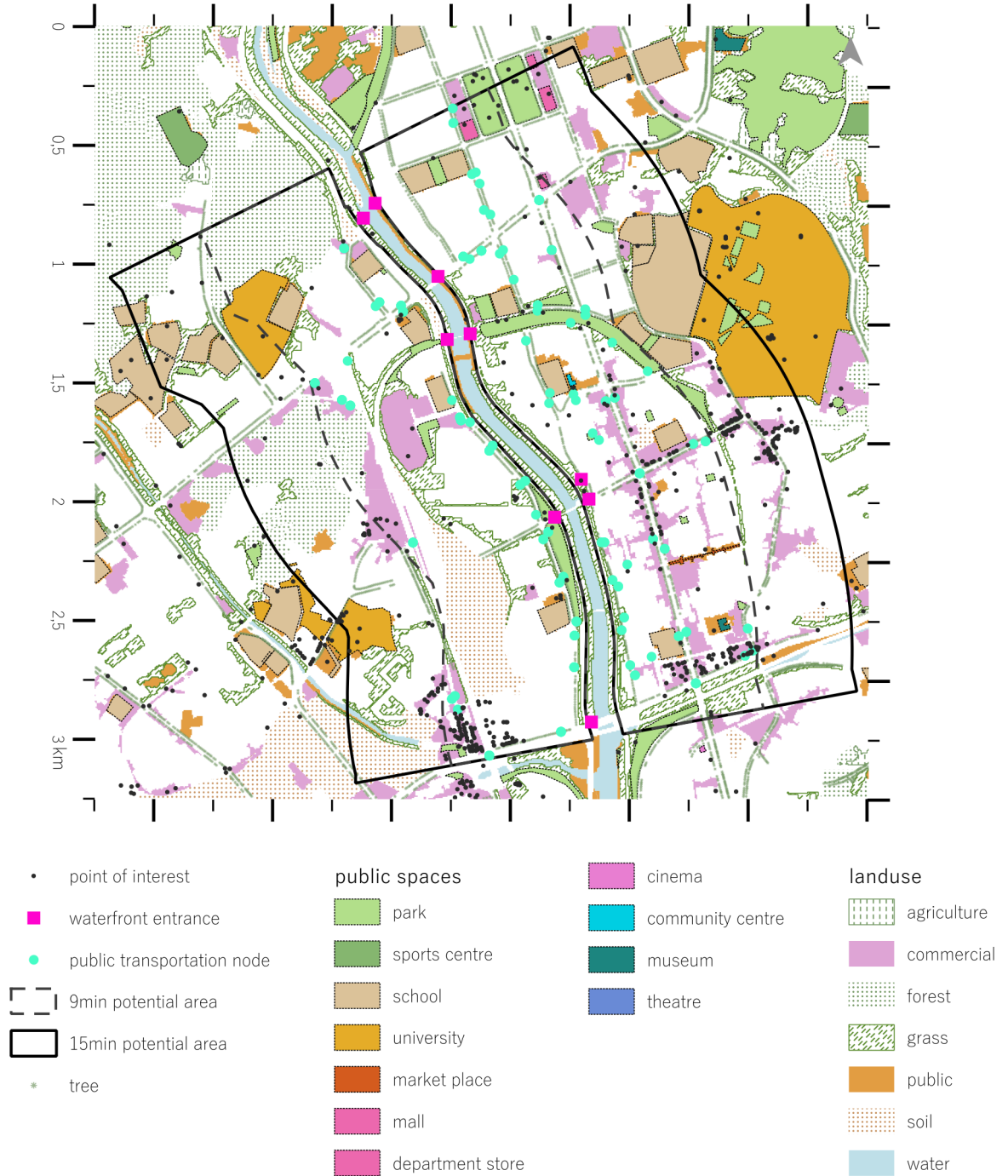


Figure 61 : Analysis of Jungrang-3's pedestrian connectivity during moderate climate

Gyeongchun railway park was a strong green spine that runs through the local area from north to south on the eastern part. However, its junction with the waterfront was a dead end, with only an elevator to connect the two principal pedestrian spaces. Important daily life locations such as the traditional market, shopping mall, and metro stops were not directly connected with the waterfront; people must take long routes in car-centric roads to reach the closest entrances.

### Intervention locations

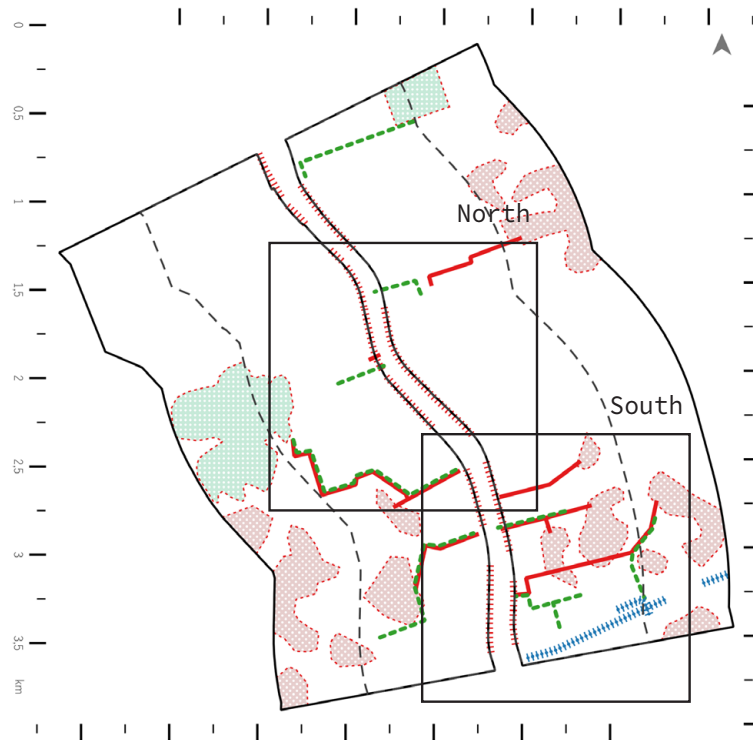
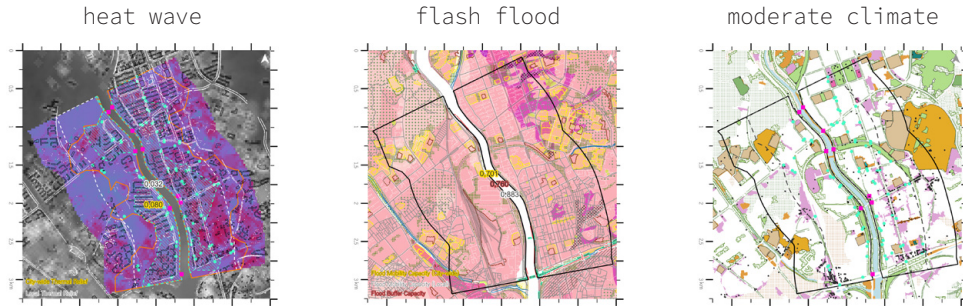


Figure 62 : Jungrang-3's conclusion map overlapping performances under three climatic scenarios

② Select spatial elements : Jungrang-3

Use climate adaptivity analysis & classification results

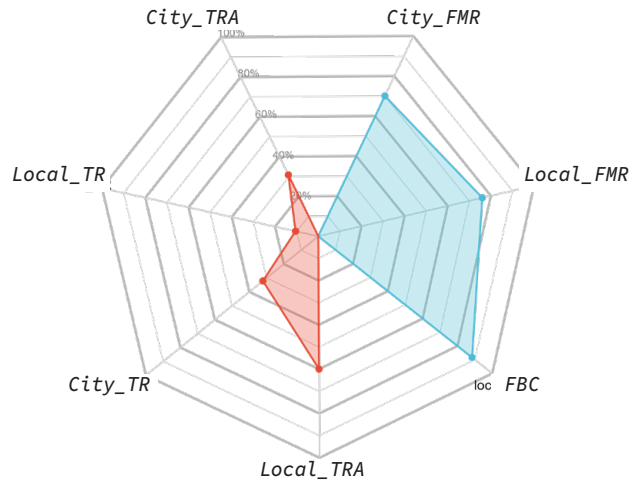


Figure 63 : Butterfly chart of Jungrang-3's comprehensive climate adaptivity

*Spatial elements*

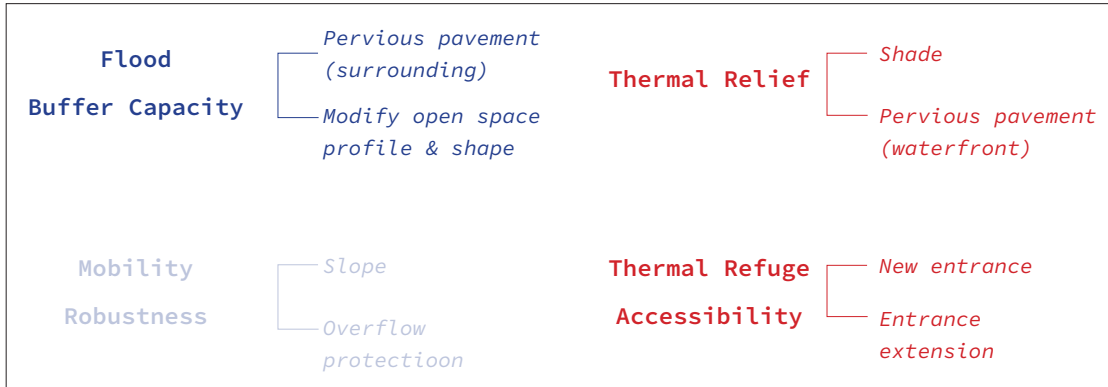


Figure 64 : Spatial elements that can be leveraged for Jungrang-3

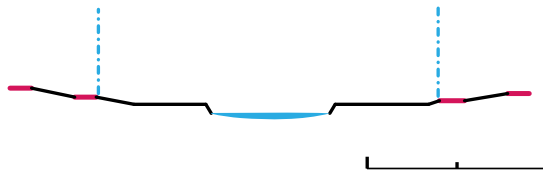


Figure 65 : Typical cross-section of Jungrang stream

Typical places in and around the waterfront were investigated to determine the applicability of spatial elements derived from the climate adaptivity analysis. Spatial configuration inside the waterfronts, important entry points, and street configuration near the integral points of interest were examined.

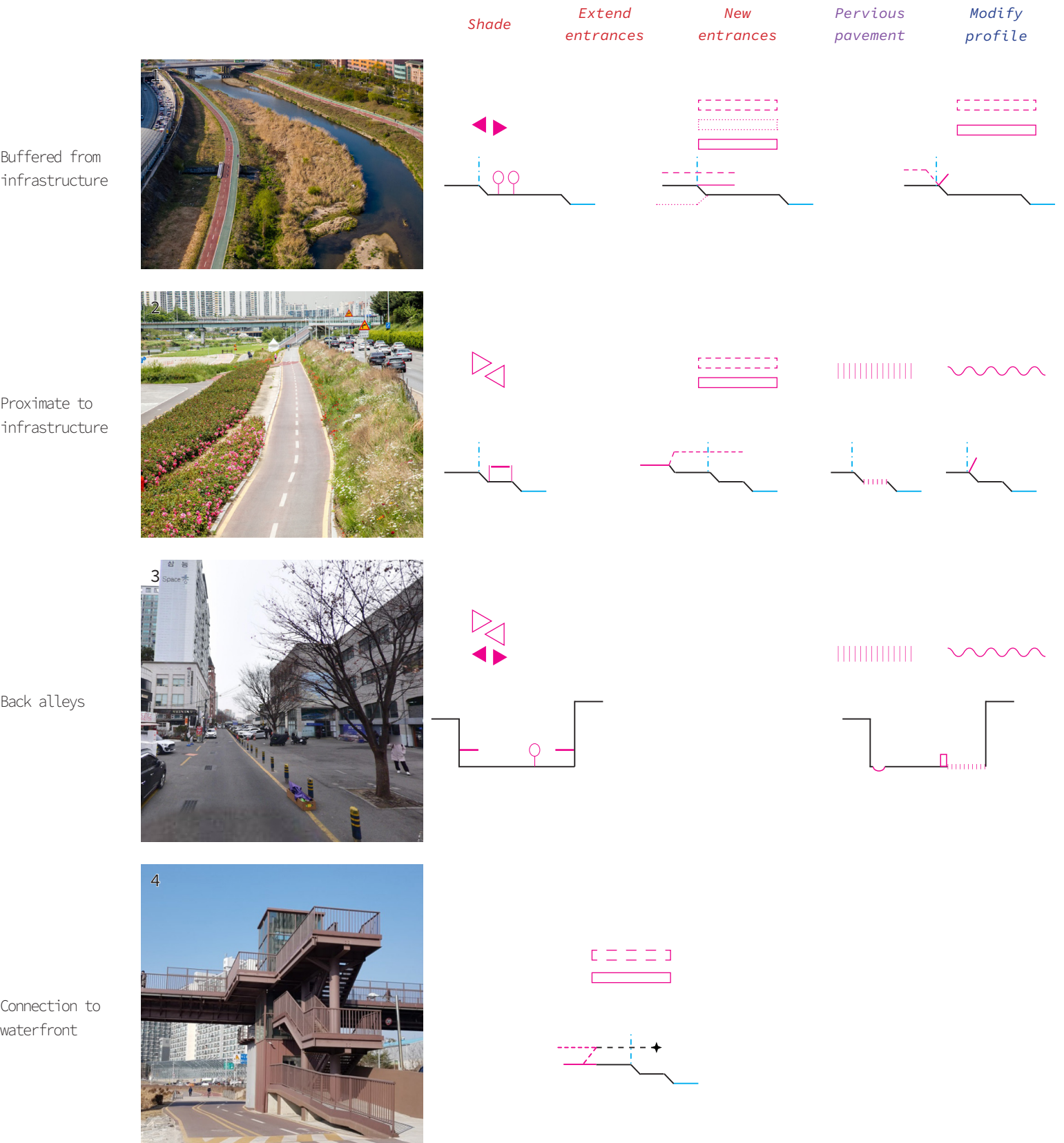


Figure 66 : Range of spatial elements applicable in typical site conditions of Jungrang-3

### ③ Spatialize elements and create variations - Jungrang-3 North

Site conditions & specific locations - North

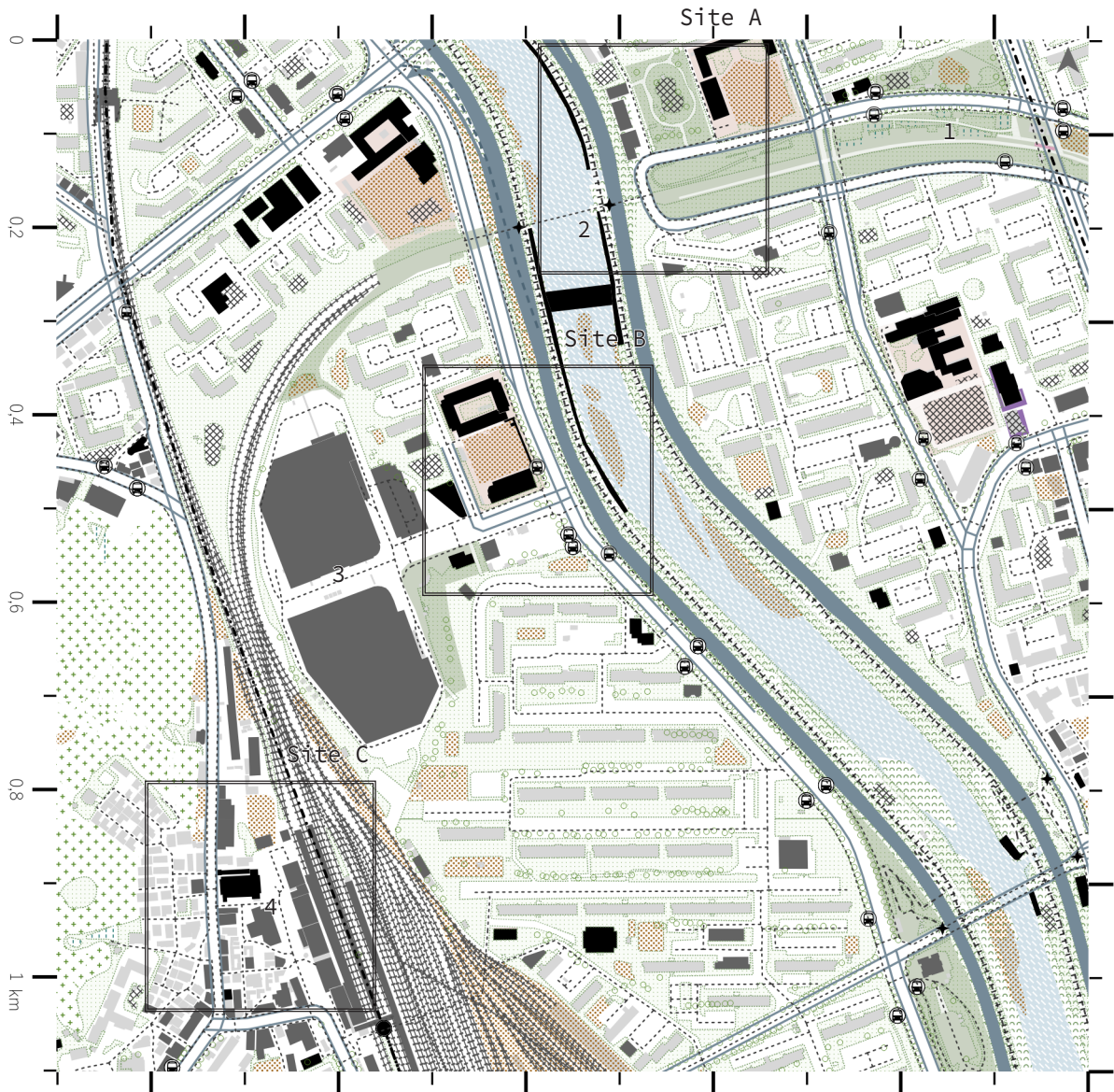


Figure 67 : Plan of Jungrang-3 North

Design interventions in the northern part of Jungrang 3 was focused in improving thermal performances. Extension and activation of Gyeongchun railway park which currently has minimal connection with the waterfront is primarily considered. Blind spots that contain important daily life activities but were not accessible to waterfronts are also included in the selection sites. In the latter case, not only the new routes are provided, but also the quality (walkability and thermal comfort) of these new connections was considered.

○ tree	----- metro lines	<b>land use</b>	<b>point of interest</b>
+ entrances	----- rail_line	agricultural	park
----- pedestrian network	waterfront adjacent roads	commercial	school
● metro stop	pedestrian area	forest	library
bus stop	bldgs	public	community centre
----- overpass		soil	water
——— autway		leisure	waterfront green
		vegetation	

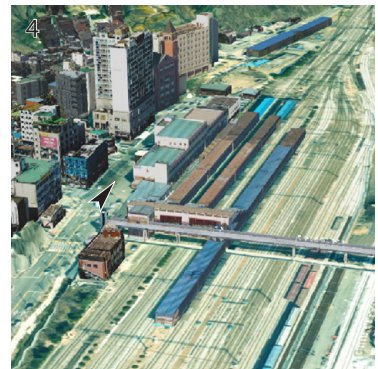
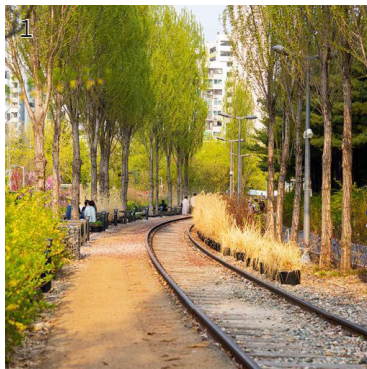


Figure 68 : Points of interests and site conditions of Jungrang-3 North

### ③ Spatialize elements - Jungrang-3 North

Spatialize elements to improve climate-adaptive performances



Site A

Site A is where the local green spine meets the waterfront. The purpose is to transform a dead end into a point of destination. The site has good potential, with a school and small park adjacent to the linear railway park. A small factory that is situated between residential apartments, the green spine and the small park is assumed to be expropriated.



Site B

Site B was originally a blind spot in city-wide thermal accessibility which consists of a huge depot-style shopping mall. Through installation of a new entrance, the car-centric road is transformed into a pedestrian-friendly street. The narrow tail of the green spine on the west becomes activated as a key part of this new green ring.



Site C

Site C is outside the local thermal accessibility isochrone due to railways that function as thick borders on its east. Thus, people are more likely to depend on the small forest to evade heatwaves. However this also implies that an active connection between this forest and the waterfront could significantly boost the quality of daily life for those who live in this site.

Figure 69 : Spatial elements applied in sites of Jungrang-3 North

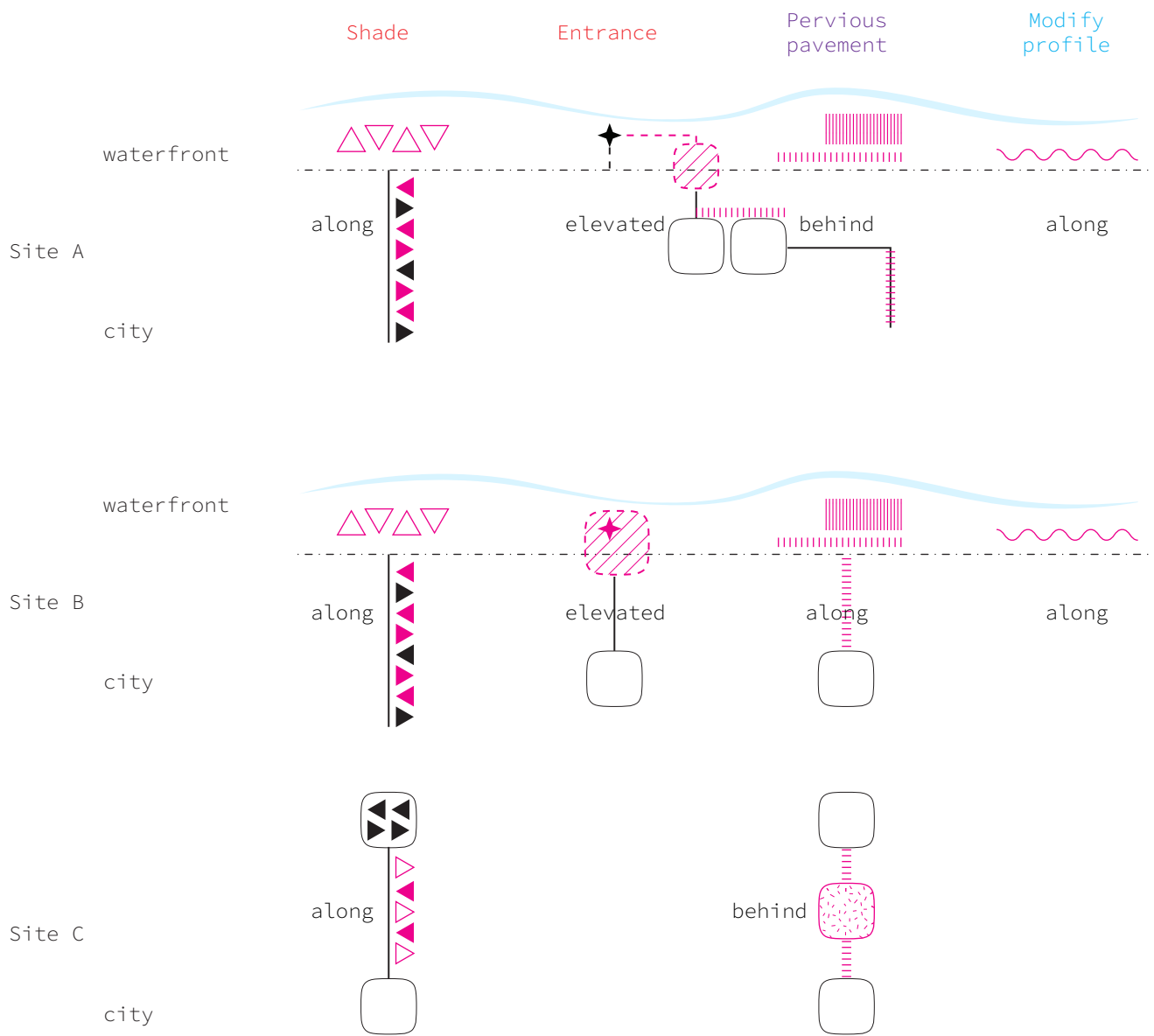
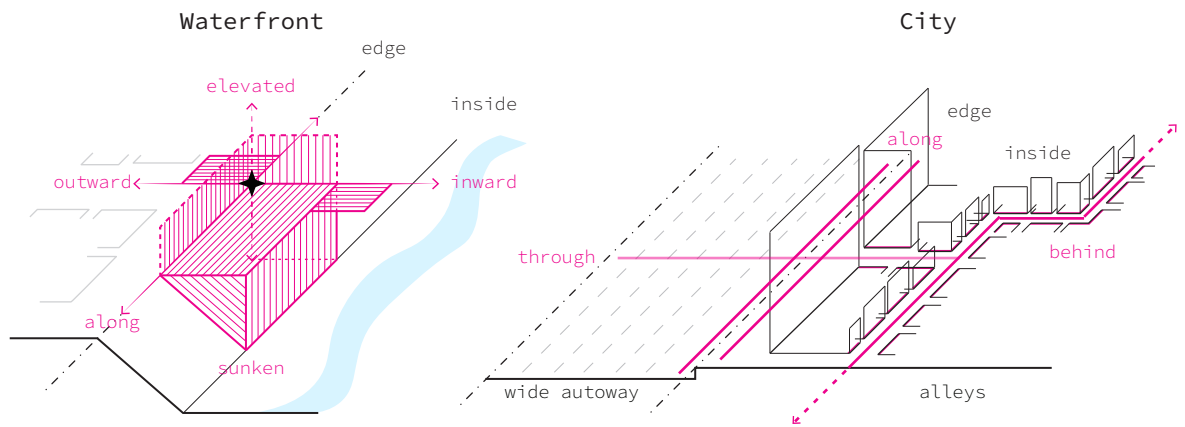
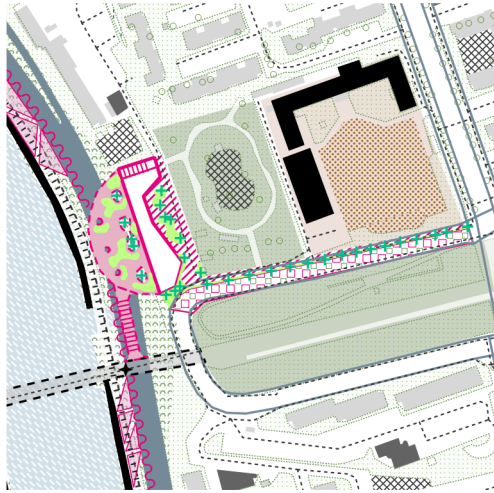
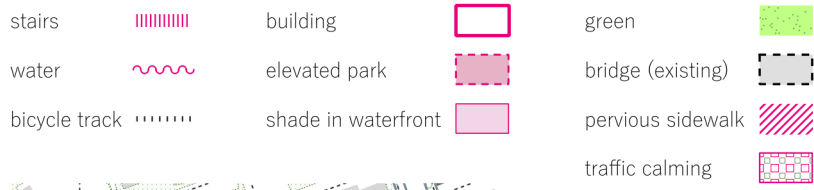
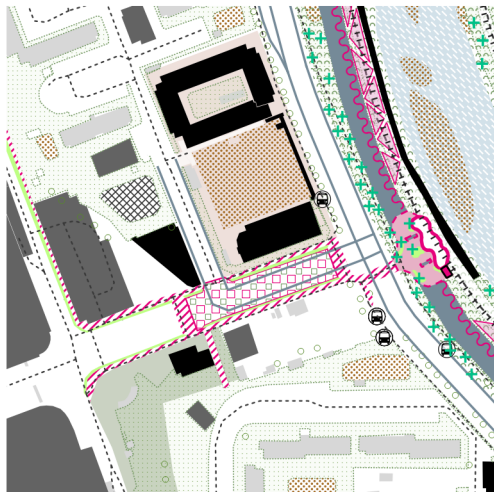
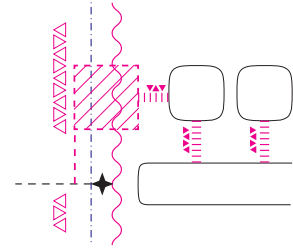


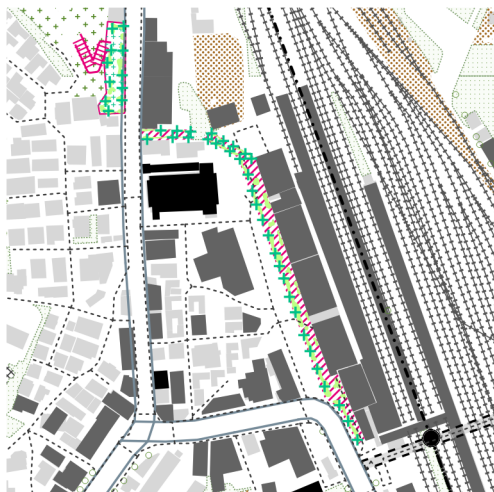
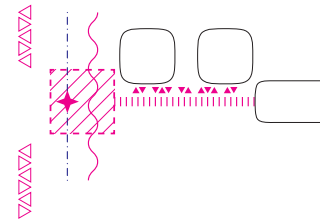
Figure 70 : Application of topological device to produce first design iteration in Jungrang-3 North's sites



Site A



Site B



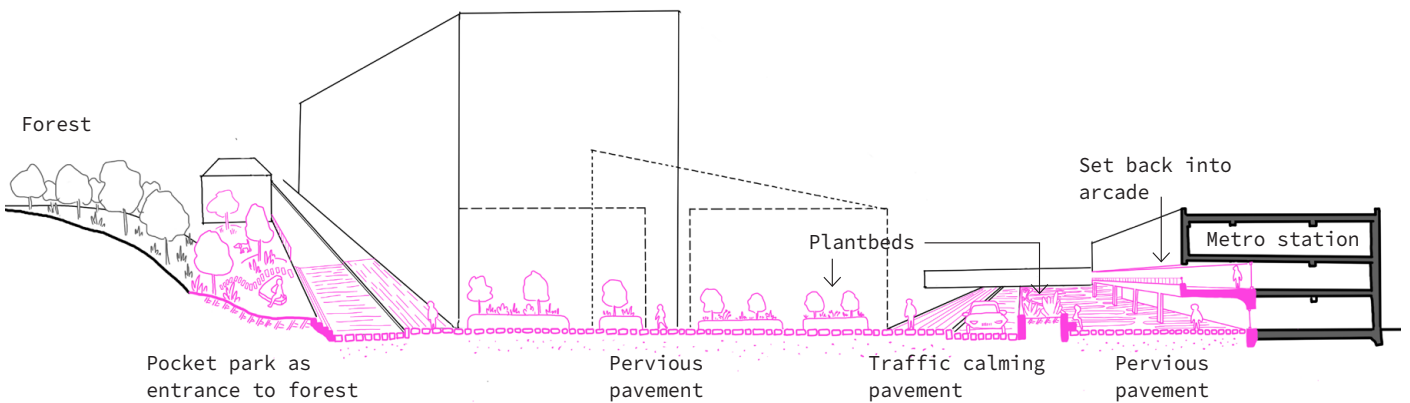
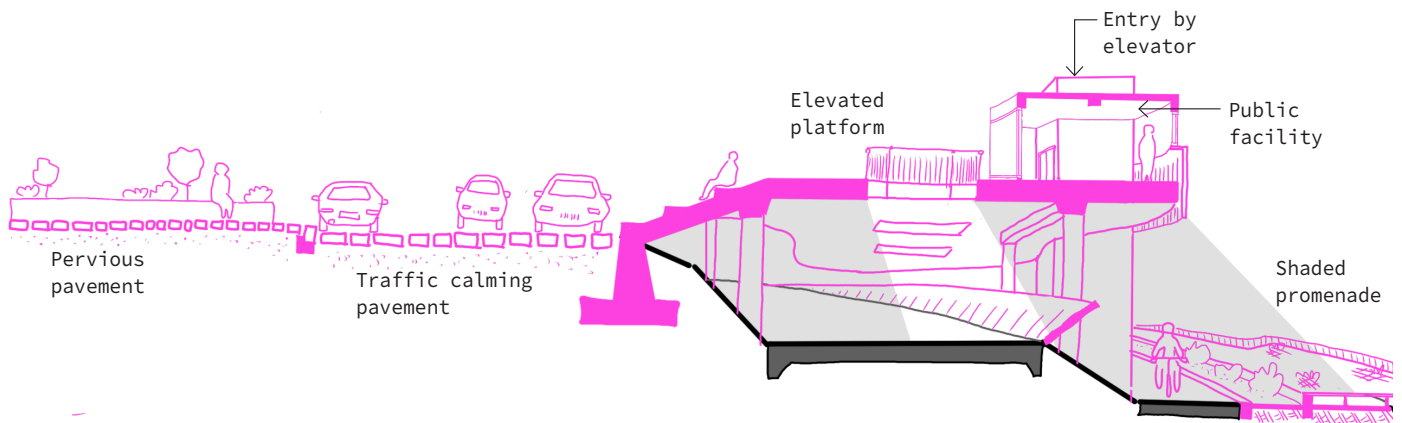
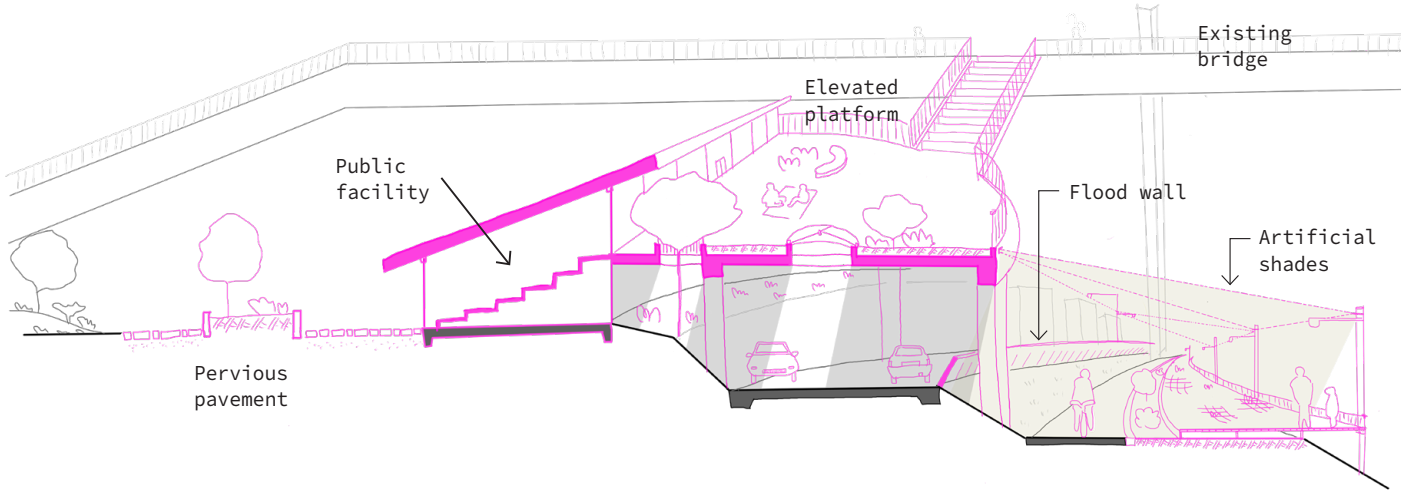
Site C



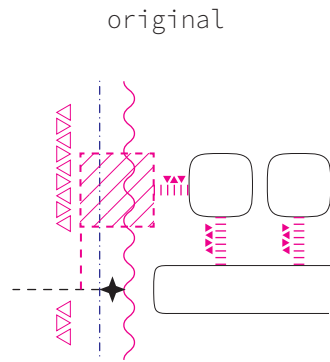
0 100 200 300 m

Figure 71 : First design iteration in Jungrang-3 North's sites: plan, extracted diagram and section perspectives

Original iterations for each site



③ Create variations - Jungrang-3 North Site A



Edge: elevated X inward

Elevated platform covers the small green strip between the motorway and the promenade. Public facility in the form of skip floor connects the ground level with the elevated platform.



Edge: ground level

In this version, the platform is located inside the expropriated area. Walkways extend toward the ground level.



Figure 72 : First design iteration in Jungrang-3 North's site A varied into two other versions using abstract diagram and visualization

④ Score & select optimal design

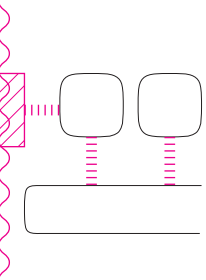
Relatively score and select most adequate design based on stakeholder discussions

Table 06 : Example evaluation of design alternatives in Jungrang-3 North site A

	original	variation #1	variation #2
Performances	3	2	1
Low-cost	2	3	1
Walkability	2	1	3

Site A →

variation #1



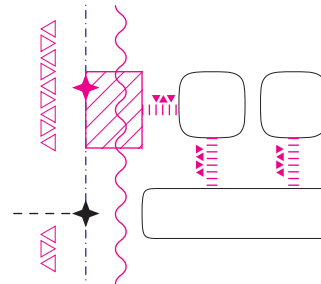
and level X along

public facility is situated  
and plot, on the same level.  
is the bridge from the upper



ed through AI X-Figura

variation #2



Edge: ground level X inward + new entrance

The motorway partially sinks to let the ground level platform extend towards the waterfront. A separate connection directly to the waterfront is installed instead of connecting it to the bridge.



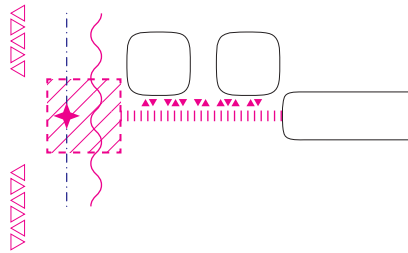
Table 07 : Example relative weights of evaluation criteria used for Jungrang-3 North site A

	Performances	Low-cost	Walkability	Weight
Performances		1	1	4
Low-cost	0		0	1
Walkability	0	1		2

$\times$   $\longrightarrow$  *original*

③ Create variations - Jungrang-3 North Site B

original

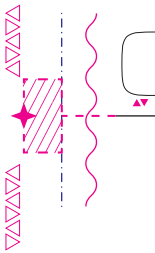


Edge: elevated X inward x new entrance

An elevated platform that extends from the sidewalk protrudes to the waterfront. The platform here is more of a plaza that faces a huge mall. The difference of level provides a sense of separation from the busy road.



var



Edge: ground level

A wide but shallow-in- towards the river only. The sidewalk is connected an elevated walkway.



Figure 72 : First design iteration in Jungrang-3 North's site B varied into two other versions using abstract diagram and visualization

④ Score & select optimal design

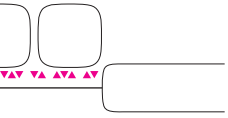
Relatively score and select most adequate design based on stakeholder discussions

Table 00 :

	original	variation #1	variation #2
Performances	1	2	3
Low-cost	2	3	1
Walkability	2	1	3

Site B →

variation #1



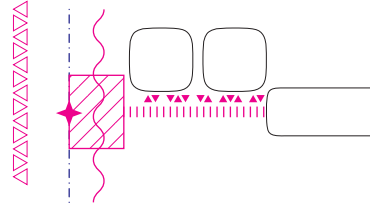
Platform X along x new entrance

Platform depth extrudes  
to reach the promenades.  
Access to the platform through



Generated through AI X-Figura

variation #2



Edge: ground level X inward x new entrance

Ground-level platform covers part of the motorway  
that has been sunk into a tunnel. This allows for  
a more direct connection between the city and the  
waterfront.



Table 00 :

	Performances	Low-cost	Walkability	Weight
Performances		0	1	2
Low-cost	1		1	4
Walkability	0	0		1

→ variation #1

### ③ Create variations - Jungrang-3 North Site C

original

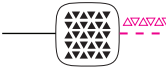


Inside: ground level x behind

The wide sidewalk beside the metro station is converted into a pedestrian-friendly, cooled-down street with ample vegetation. The ground floor of the metro station is set back to provide additional shade and shelter for people. This new path leads to a new park that was originally a small recycling junk yard which is the entry point to the small forest.



var



Inside: el

The elevated walkway t above the railway is e station whose 1st floor path. People have mini reach the small forest the walkway becomes a new park is also eleva facilities can be inst



Figure 72 : First design iteration in Jungrang-3 North's site C varied into two other versions using abstract diagram and visualization

### ④ Score & select optimal design

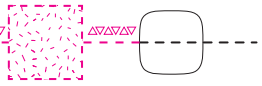
Relatively score and select most adequate design based on stakeholder discussions

Table 00 :

	original	variation #1	variation #2
Performances	3	2	1
Low-cost	3	2	1
Walkability	1	2	3

Site C →

variation #1



Elevated X behind

that is already installed  
 extended along the metro  
 or is connected to this new  
 imal need to climb stairs to  
 . Shaded sidewalk beneath  
 shaded marketplace. The  
 ated, under which public  
 called.



ed through AI X-Figura

variation #2



Edge: elevated X behind x existing POI

The idea of elevated walkway is identical to variation 1, except that this version makes use of the roofs of existing buildings. The access to railway platforms is most convenient in this case, and the public spaces inside the station are activated by increased foot traffic. This scheme is most effective in creating a chain of public programs that eventually links between two important public spaces that provide thermal comfort during heatwaves.



Table 00 :

#2		Performances	Low-cost	Walkability	Weight
	Performances		1	0	2
	Low-cost	0		0	1
	Walkability	1	1		4

×
→ *variation #2*

### ③ Spatialize and interconnect strategies - Jungrang-3 South

#### Site conditions & specific locations - South

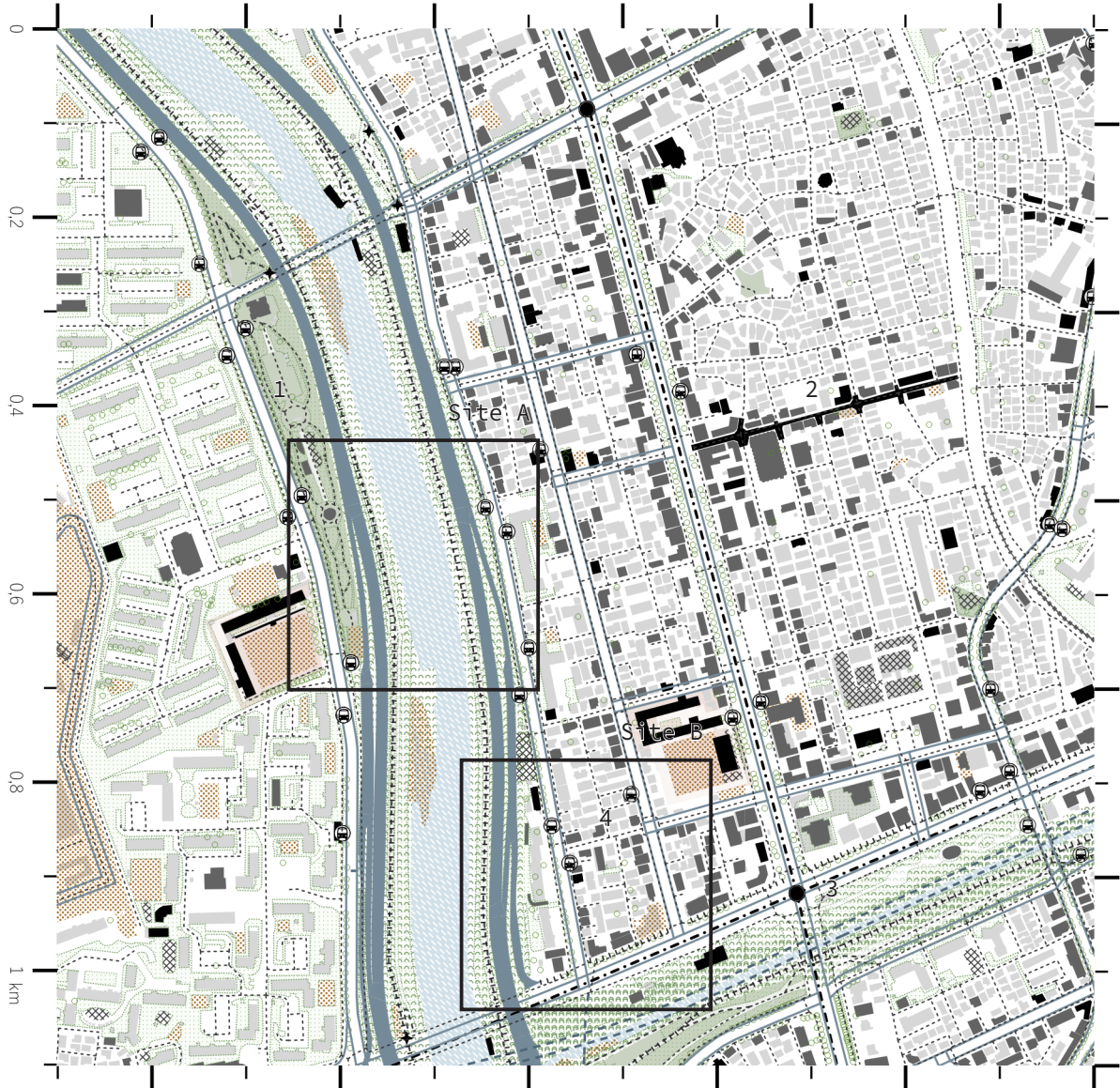


Figure 75 : Plan of Jungrang-3 South

The southeastern part of Jungrang 3's local area is distinct from the rest, marked by densely packed low-rise buildings. Design focus in this area is on improving thermal comfort of routes between important points of interest and the waterfront. The inundated paths that lie between the metro stop and the waterfront were also selected for demonstration. In these places, some sections of the road were protected to allow traffic during severe rainfalls.

○ tree	--- metro lines	land use	point of interest
+ entrances	++++ rail_line	agricultural	park
----- pedestrian network	waterfront adjacent roads	commercial	school
● metro stop	pedestrian area	forest	library
bus stop	bldgs	public	community centre
--- overpass		soil	water
— highway		leisure	waterfront green
		vegetation	

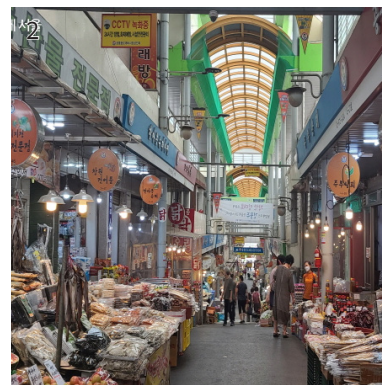


Figure 76 : Points of interests and site conditions of Jungrang-3 South

### ③ Spatialize elements - Jungrang-3 South



Site A

Site A is a section of the waterfront where it is flanked by strips of green space. In the west, an in-between vacant land between the apartments and the motorway was programmed as a neighborhood park; on the other side, a narrow strip of promenade was formed on top of the riverbank. This promenade marks the western edge of the low-rise mix-use district.



Site B

Site B includes a wide road vulnerable to floods that lies between the metro and the waterfront. However, there is no entrance installed in this corner, and people must cross the waterfront along the seven-lane road surrounded by tall towers to access it. A new entrance in this site presents an opportunity to activate human-scale back alleys instead of car-centric roads.

Figure 77 : Spatial elements applied in sites of Jungrang-3 South

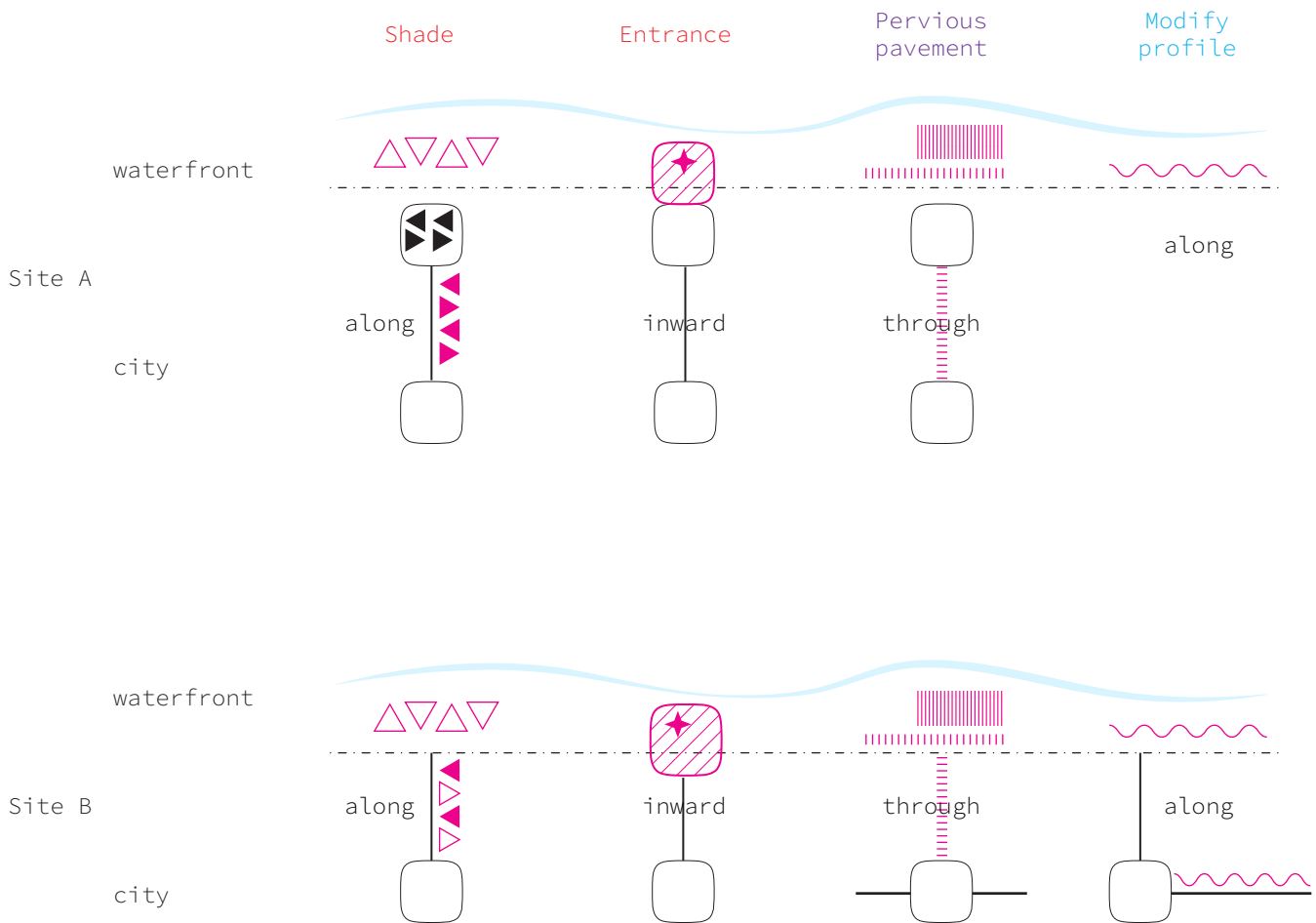
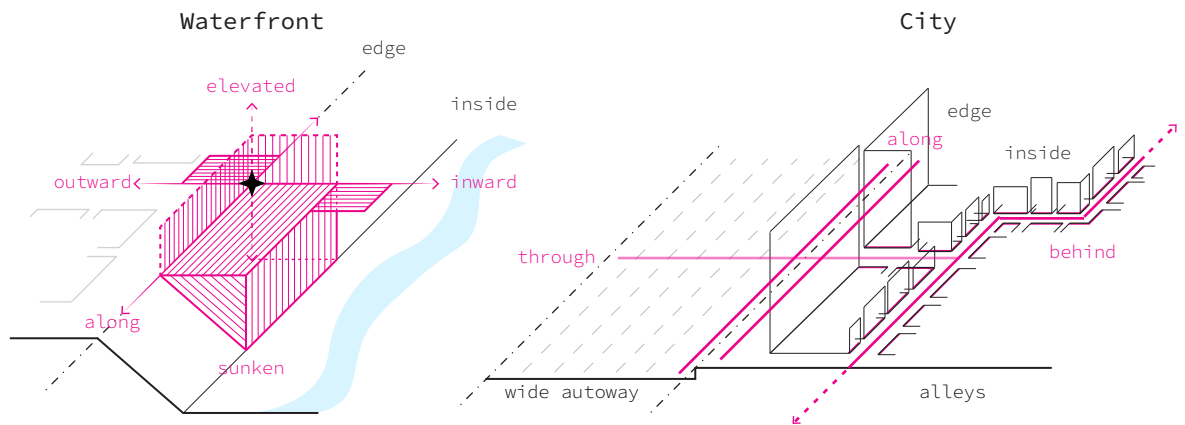
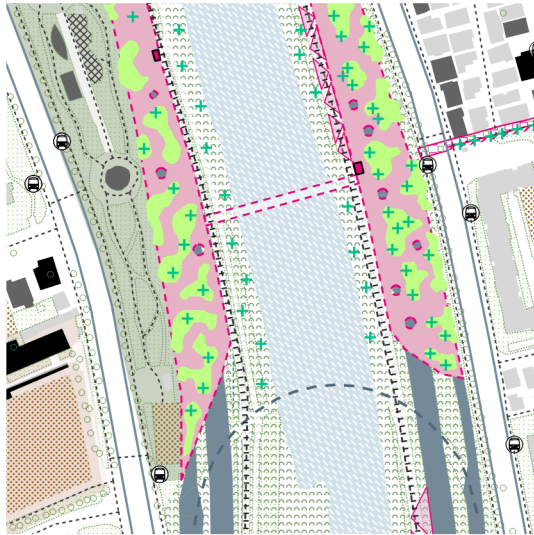
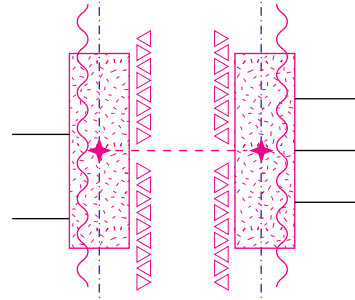


Figure 78 : Application of topological device to produce first design iteration in Jungrang-3 South's sites



Site A



- ◆ new entrance
- + natural shade
- slope
- - - motorway overpass
- ~~~~~ flood resistance
- building
- ▨ elevated park
- ▨ shade in waterfront
- green
- elevator
- ▨ pervious sidewalk
- ▨ traffic calming
- ▨ bridge (new)



Site B

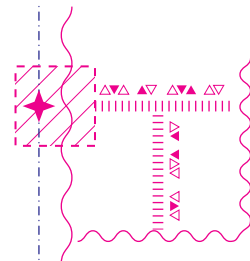
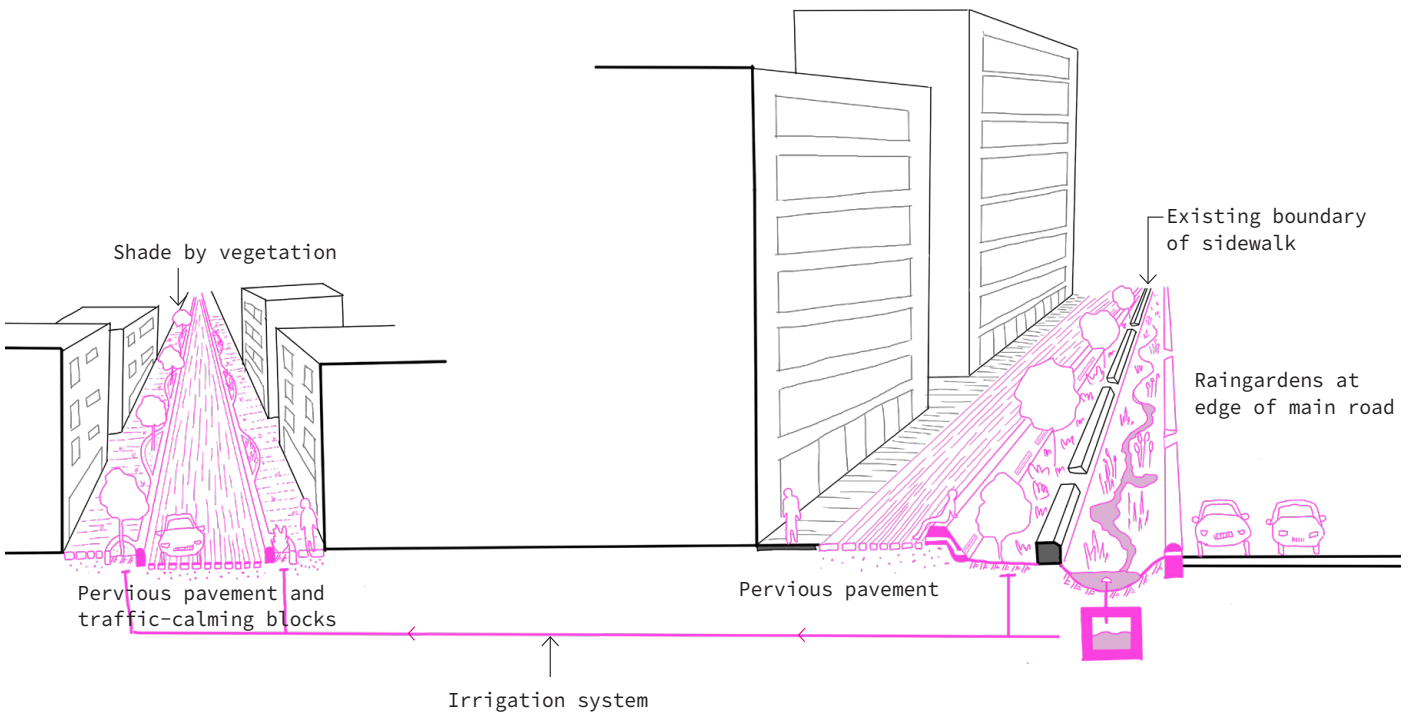
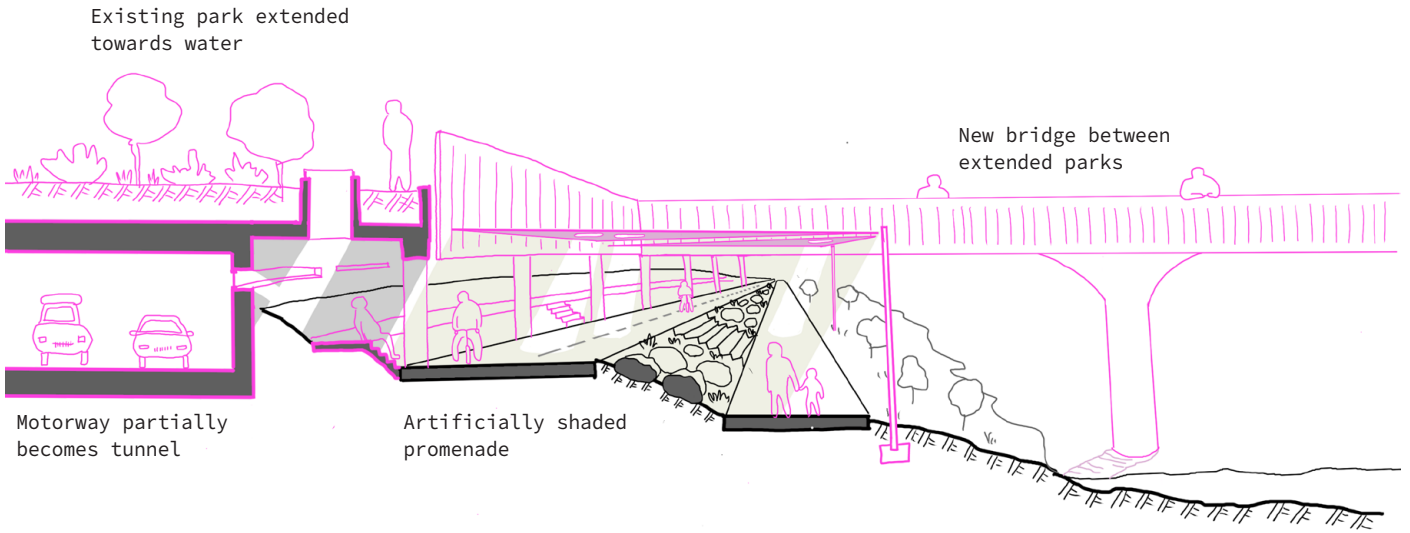
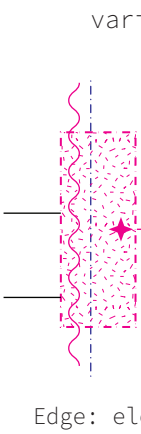
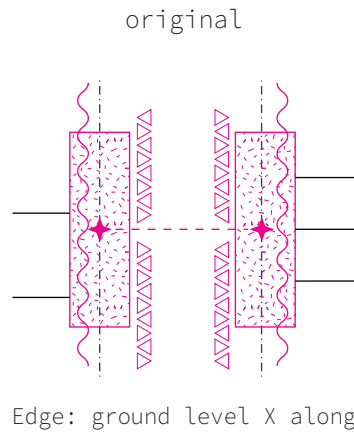


Figure 79 :First design iteration in Jungrang-3 South's sites: plan, extracted diagram and section perspectives

Original versions of design for each site



③ Create variations - Jungrang-3 South Site A



Both linear green spaces are extended towards the river sustaining their ground level. This means that the corresponding section of the motorways are converted into tunnels. The two opposite platforms are then connected and function as one space together.

This version elevates so that the motorways. The effect of producing extruding further towa



Figure 80 : First design iteration in Jungrang-3 South's site A varied into two other versions using abstract diagram and visualization

④ Score & select optimal design

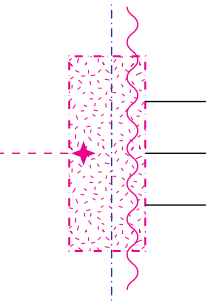
Relatively score and select most adequate design based on stakeholder discussions

Table 00 :

Site A →

	original	variation #1	variation #2
Performances	1	3	2
Low-cost	1	2	3
Walkability	3	2	1

variation #1



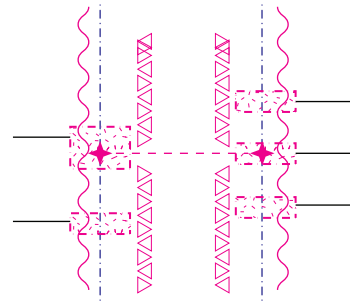
elevated X along

the extended platforms do not need alterations. The shading is maximized by turning towards the water.



generated through AI X-Figura

variation #2



Edge: elevated X inward

This version fragments the first variation so that the platforms form an elevated network that links important points of interest. In this case, not all of them have direct connection to the waterfront.



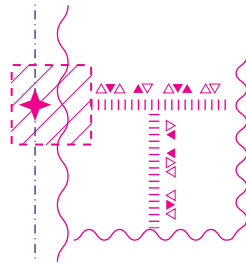
Table 00 :

	Performances	Low-cost	Walkability	Weight
Performances		2	0	1
Low-cost	1		0	2
Walkability	1	1		4

original & variation #1

③ Create variations - Jungrang-3 South Site B

original

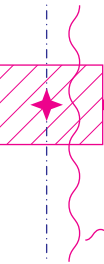


Edge: sunken X along

Roadside rain gardens are formed between the sidewalk and the car lanes. Benches protect overflow into sidewalks and the sunken garden temporarily store runoff water and keep lanes dry.



var



Inside: e

Fabric shades are installed to reduce sky view factor. Benches are replaced with permeable paving to increase evaporation from surface. Waterfront edge is ideal.



Figure 81 : First design iteration in Jungrang-3 South's site B varied into two other versions using abstract diagram and visualization

④ Score & select optimal design

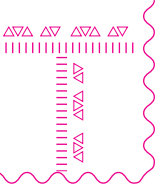
Relatively score and select most adequate design based on stakeholder discussions

Table 00 :

	original	variation #1	variation #2
Performances	3	2	1
Low-cost	1	2	3
Walkability	2	3	1

Site B →

variation #1



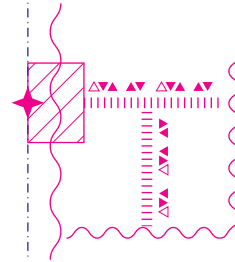
Elevated X along

called between buildings to  
 . Asphalt and clay bricks  
 various pavement to increase  
 ce. Variations on the  
 entical to Site A - North.



red through AI X-Figura

variation #2



Inside: ground level X along

Shade is limited to pedestrian part of the  
 road, like the pervious pavement. This limited  
 intervention is compensated by clear delineation  
 of pedestrian area through vegetation.



Table 00 :

#2	Performances	Low-cost	Walkability	Weight
	Performances	1	1	4
	Low-cost	0	0	1
	Walkability	0	1	2

$\times$   $\longrightarrow$  *original*

### 3.6.2 Implementation of developed design process in Hongje 3

Table 00 :

<b>Location</b>	North-west of Seoul, downstream
<b>Size</b>	85.5m width X 904m length
<b>Climate adaptivity</b>	Type 3 Vulnerable pedestrian network if flooded
<b>Spatial conditions</b>	Shadowed by overpass motorway, narrowest district stream



Figure 82 : Location of waterfront Hongje-3

Hongje 3 is the second-last segment of a very continuous stream that runs uninterrupted by other tributaries through mostly low-rise residential areas. This segment's southern surrounding is also a low-rise residential area whereas the northern part is more mixed with apartments and offices. Its length is defined by the intersection with Bulgwang stream on the west, and by a point where pedestrians are forced to exit the sunken waterfront on the east. Like most of the stream, this segment is roofed by an arterial motorway called the inner circulation line, which makes the already narrow waterfront even more enclosed. The huge columns of the overpass, together with structural support for the adjacent roads, creates colonnades of different sizes throughout the waterfront.



Figure 83 : Waterfront and local area boundaries of Hongje-3



Figure 84 : Birdseyeview of waterfront Hongje-3 and its local area



Figure 85 : Relationships with adjacent infrastructures in Hongje stream

① Identify effective design locations : Hongje-3

Overlap three scenarios: heatwaves, flash floods, and moderate climate

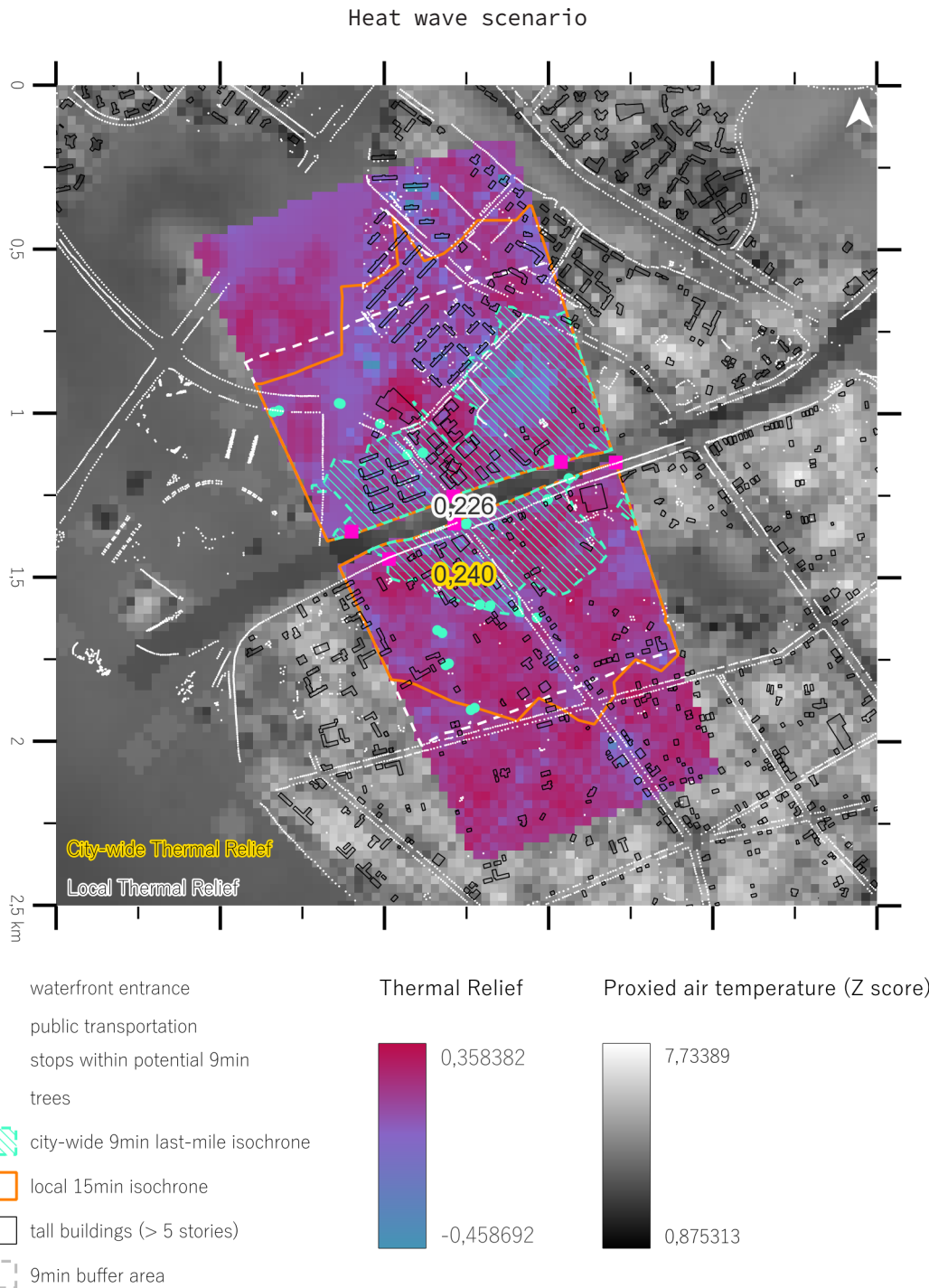


Figure 86 : Analysis of Hongje-3's climate adaptive performances against heatwaves

Thermal relief is among the highest of all the analyzed waterfronts, thanks to the low sky view factor as result of the overpass. The northern local area performed worse than the south and points to the thermal comfort of the routes towards the waterfront. Thermal refuge accessibility, especially city-wide, showed very bad performance, indicating a great imbalance between demand and reachability. Given the even distribution of entrances on a small waterfront, this implies that the distribution of public transportation was determined without consideration of waterfront access.

### Flash flood scenario

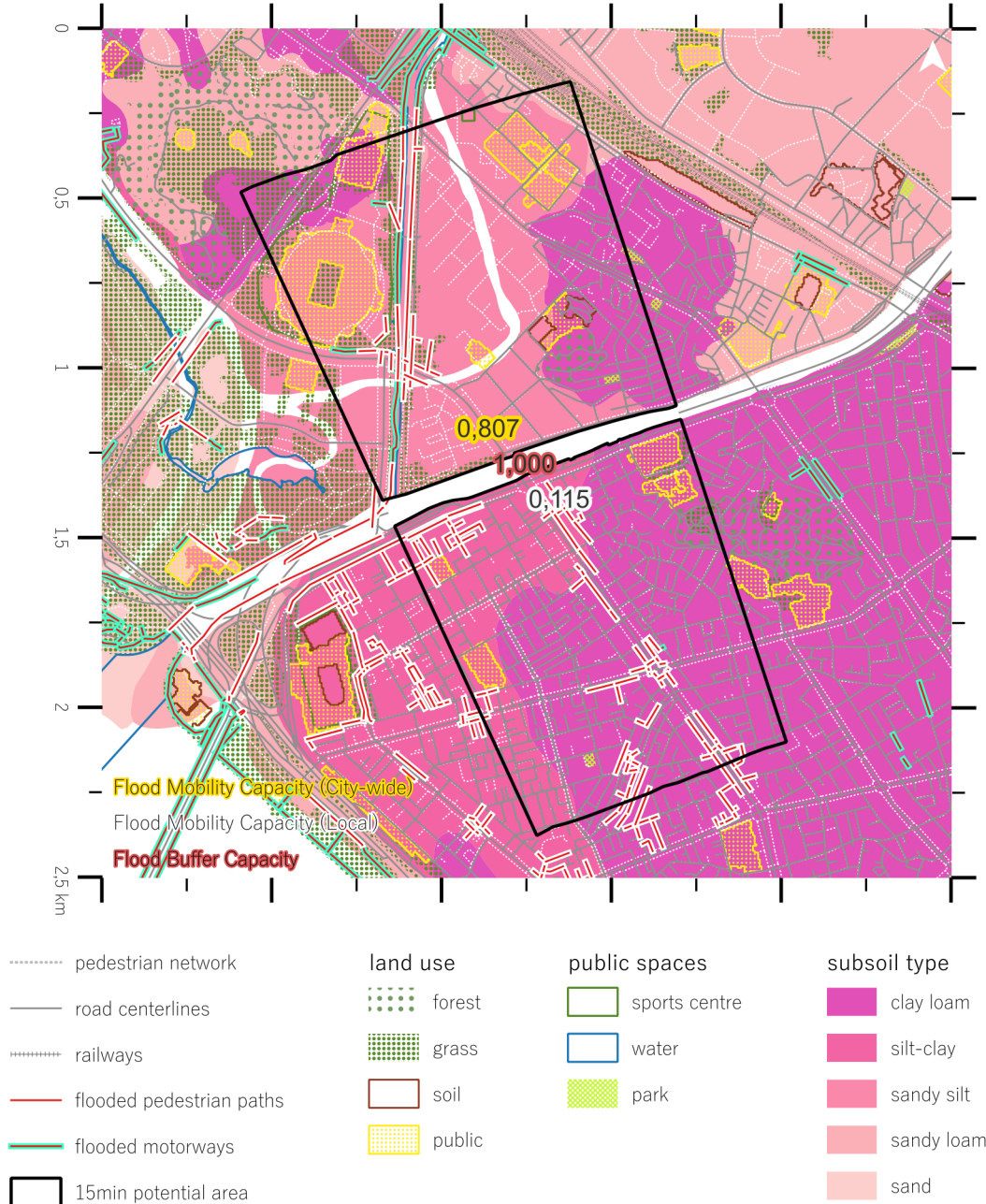


Figure 87 : Analysis of Hongje-3's climate adaptive performances against flash floods

Despite the low risk of overflow, the extent of disruption that local pedestrians will experience was much higher than automobile drivers. Most of the southern local area consisted of inadequate soil type that will deteriorate the effect of nature-based solutions. In this region, not only wide roads were under risk of inundation, but also back alleys were endangered. The paths that were under risk of in northern local area were next to a tributary stream, from which water will flow southwards.

Moderate climate

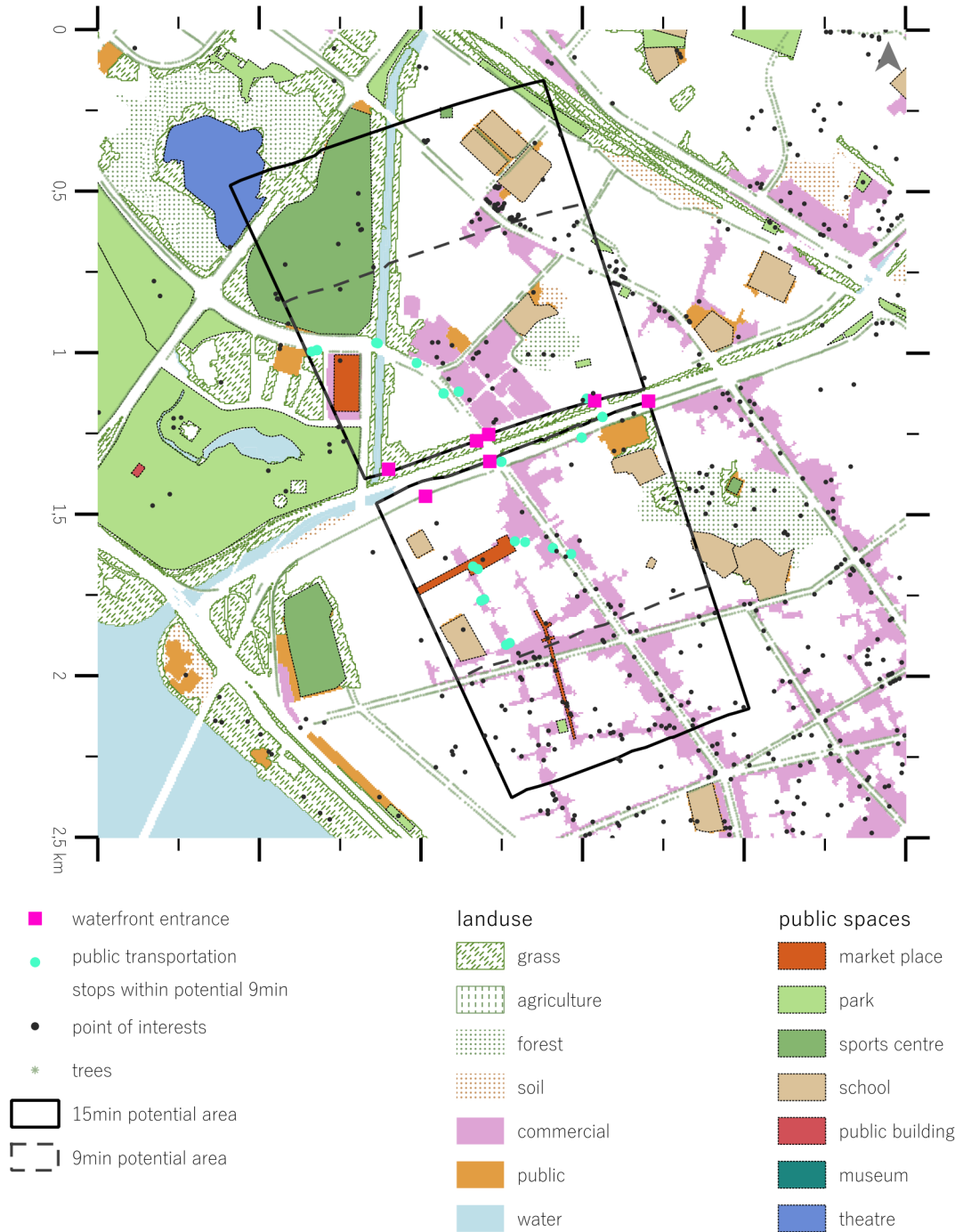
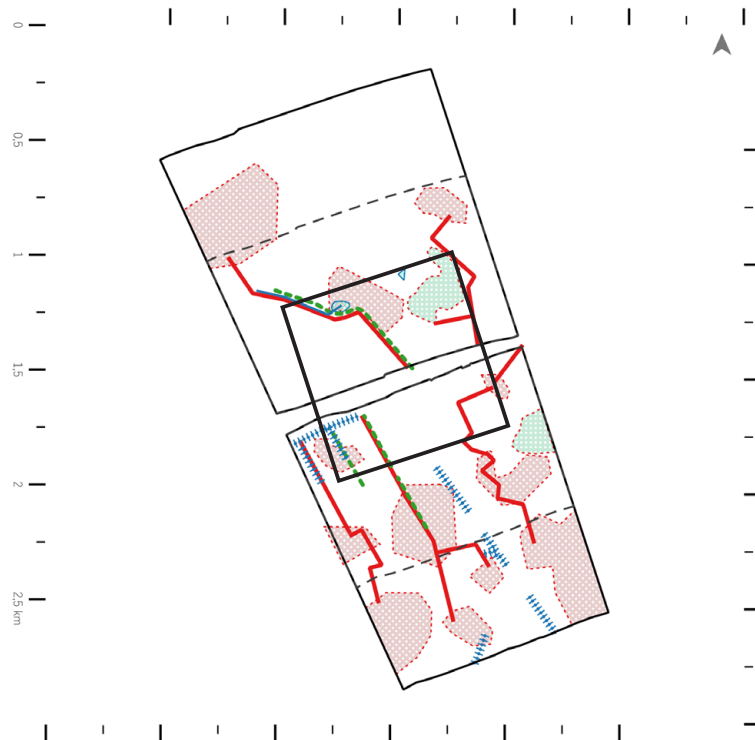
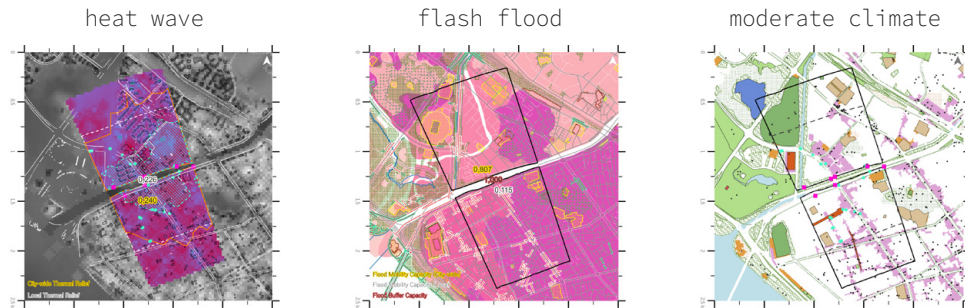


Figure 88 : Analysis of Hongje-3's pedestrian connectivity during moderate climate

An axis penetrates through the local area from north to south, flanked by commercial districts. Behind them are public spaces that perform key functions in daily life: schools, market places, sports facilities. However, they lie disconnected from each other, as well as with the waterfront. Mangwon market in the southern part is a popular point of destination that has the potential to activate back alleys.

### Intervention locations



- heat relief access to waterfront
- induce flow
- ||||| flood resistance
- ||||| possible wadi
- ||||| relatively cooler area
- ||||| hot areas without waterfront access
- 15min potential area
- 9min potential area

Figure 89 : Hongje-3's conclusion map overlapping performances under three climatic scenarios

② Select spatial elements : Hongje-3

Use climate adaptivity analysis & classification results

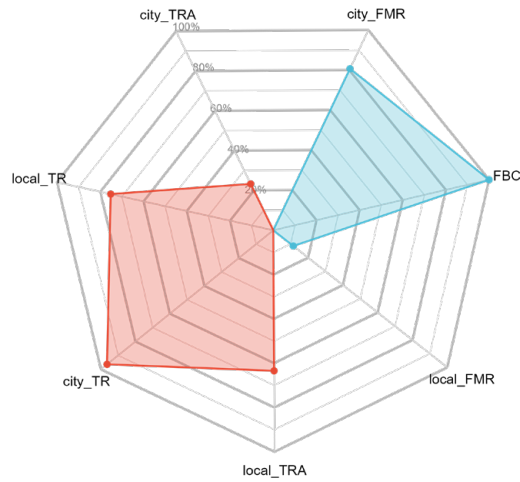


Figure 90 : Butterfly chart of Hongje-3's comprehensive climate adaptivity

*Spatial elements*

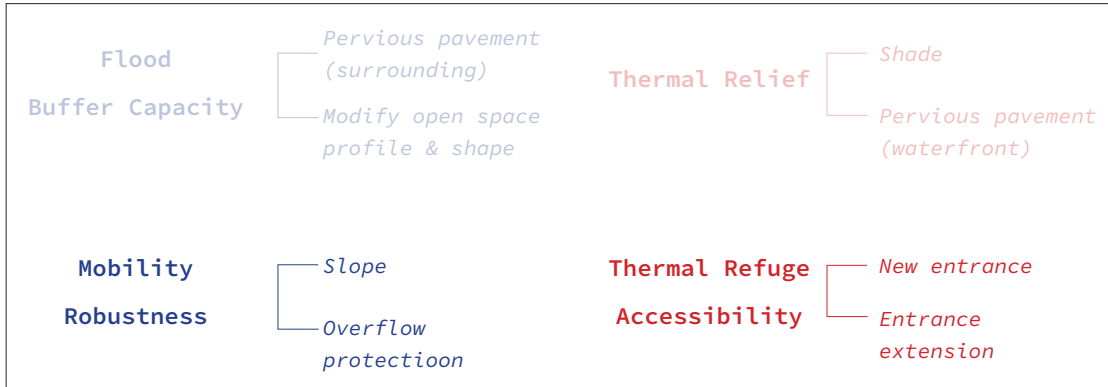


Figure 91 : Spatial elements that can be leveraged for Hongje-3

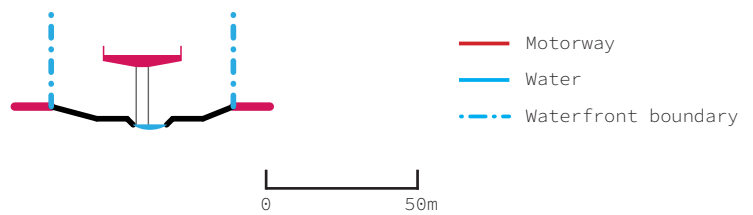


Figure 92 : Typical cross-section of Hongje stream

Site conditions & applicable range of elements

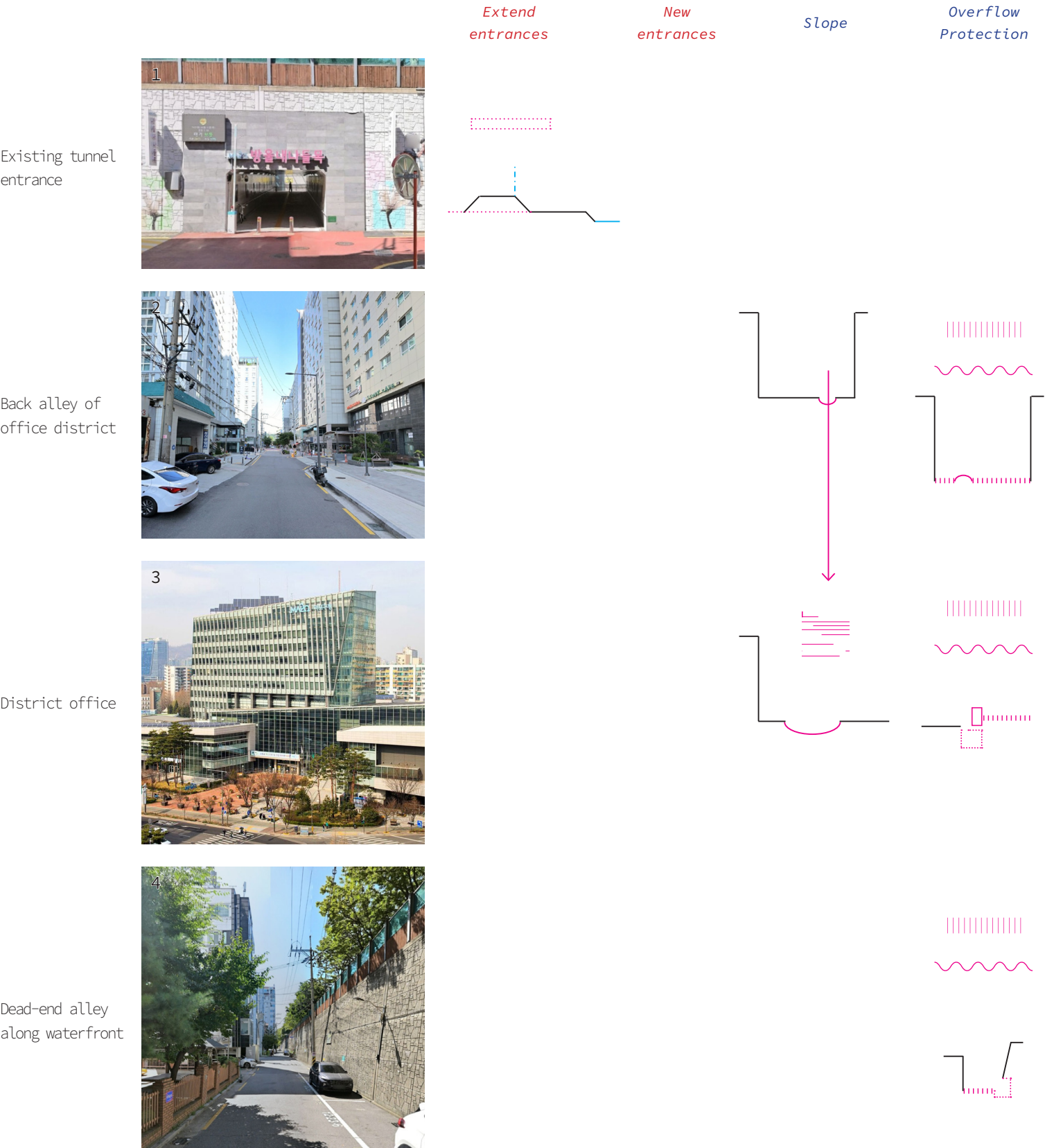


Figure 93 : Range of spatial elements applicable in typical site conditions of Hongje-3

### ③ Spatialize elements and create variations

#### Site conditions & specific locations

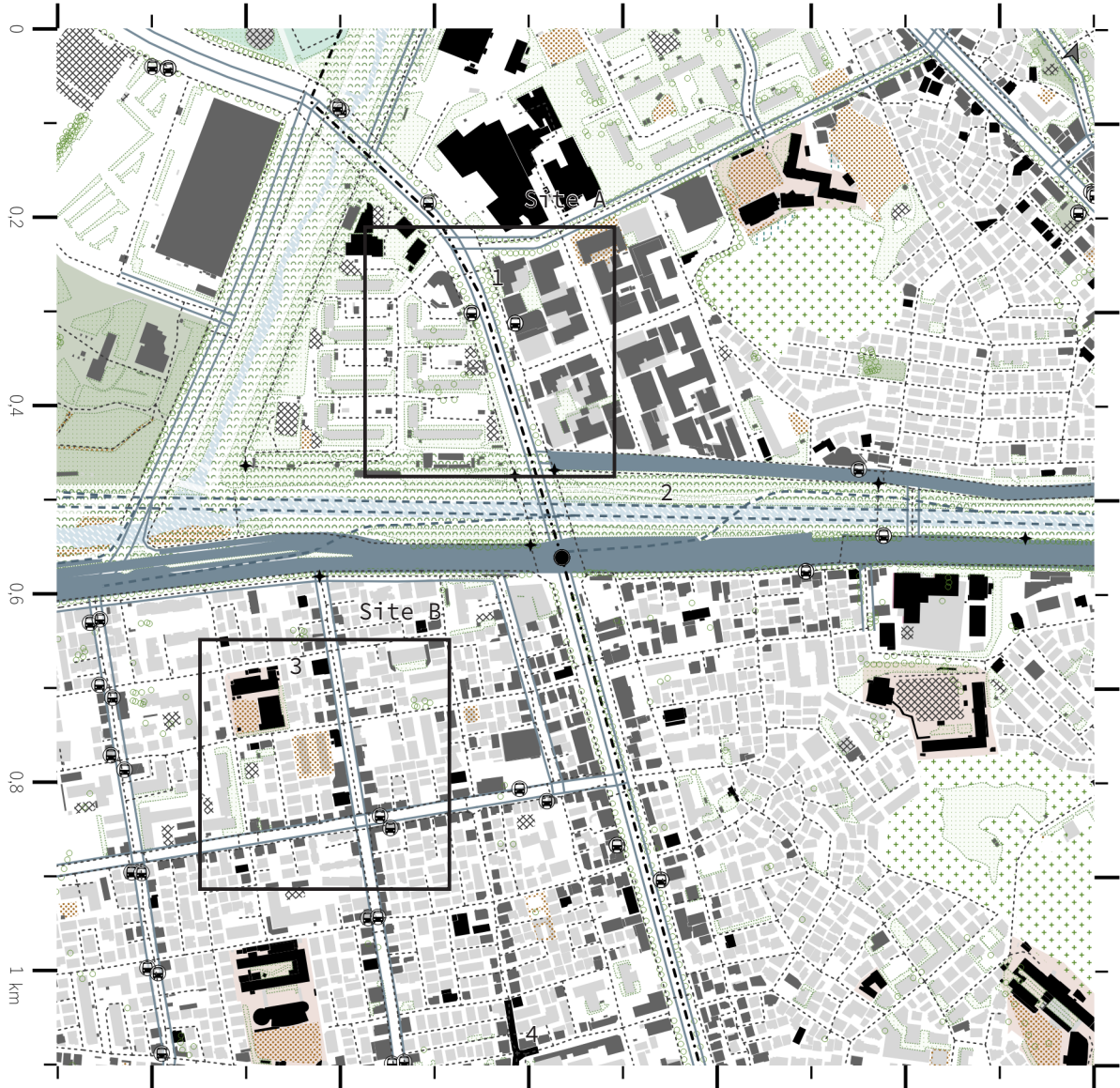


Figure 94 : Plan of Hongje-3

The main purpose of design intervention was the enhancement of thermal comfort of important routes. Although Hongje 3's city-wide thermal accessibility was poor, it could not be resolved with additional entrances in Hongje 3; modification of bus routes would be necessary. Therefore, the focus was shifted to improving thermal comfort of routes that connect key points of interest to waterfronts. Besides this aspect, mobility robustness under floods was also considered.

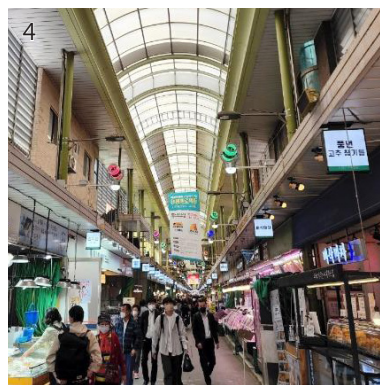
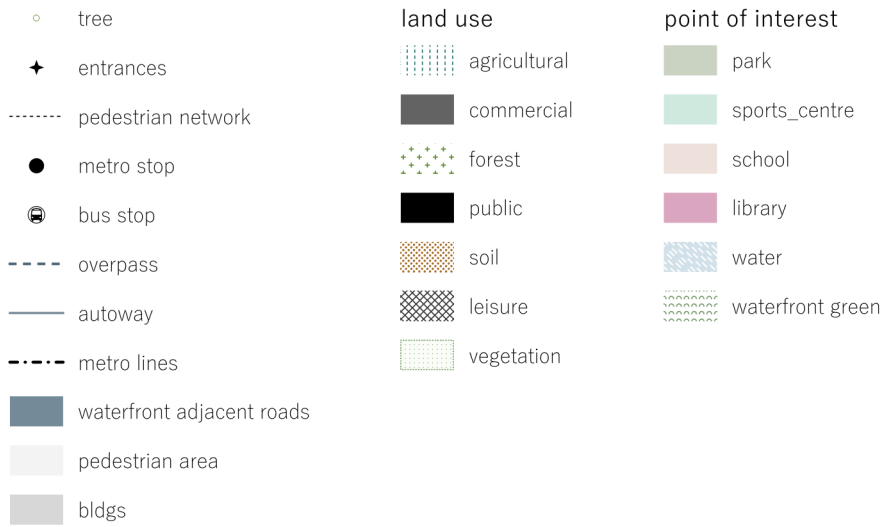
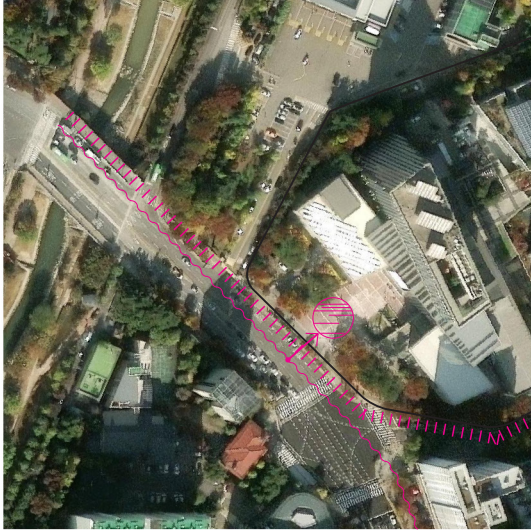
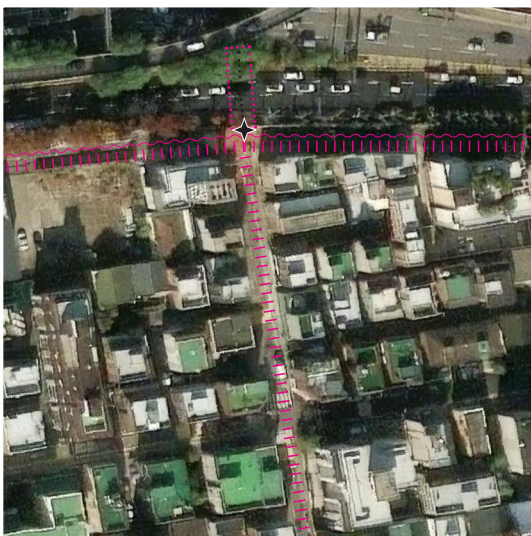


Figure 95 : Points of interests and site conditions of Hongje-3



Site A

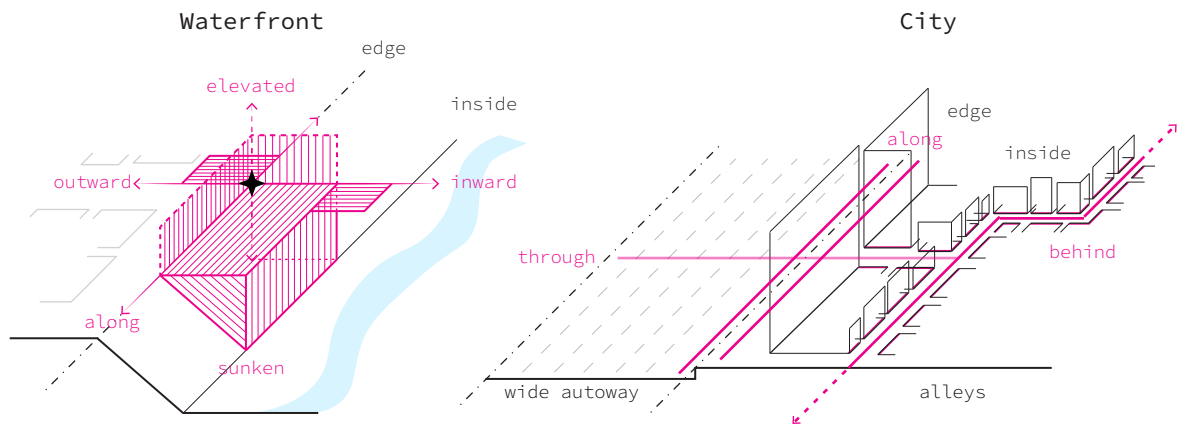
Site A is where the high-rise district office is located. Its plaza that surrounds the building provides good basis for a well-shaded pedestrian path that can be led through the mix-use office district instead of along the car-centric wide road. Furthermore, the spatial distinction between the car lanes and the plaza can be used to protect overflow and the plaza can also function as a wadi when severe rainfall occurs.



Site B

Many alleys connected to the waterfront entrance in Site B are also subject to floods when the waterfront overflows. Therefore, design elements must be combined to improve both thermal comfort and flood resistance. Widened tunnel connection, together with explicit connection to important points of interest, has the potential to transform the dead end alley into a local favorite spot.

Figure 96 : Spatial elements applied in sites of Hongje-3



Entrance

Slope

Overflow protection

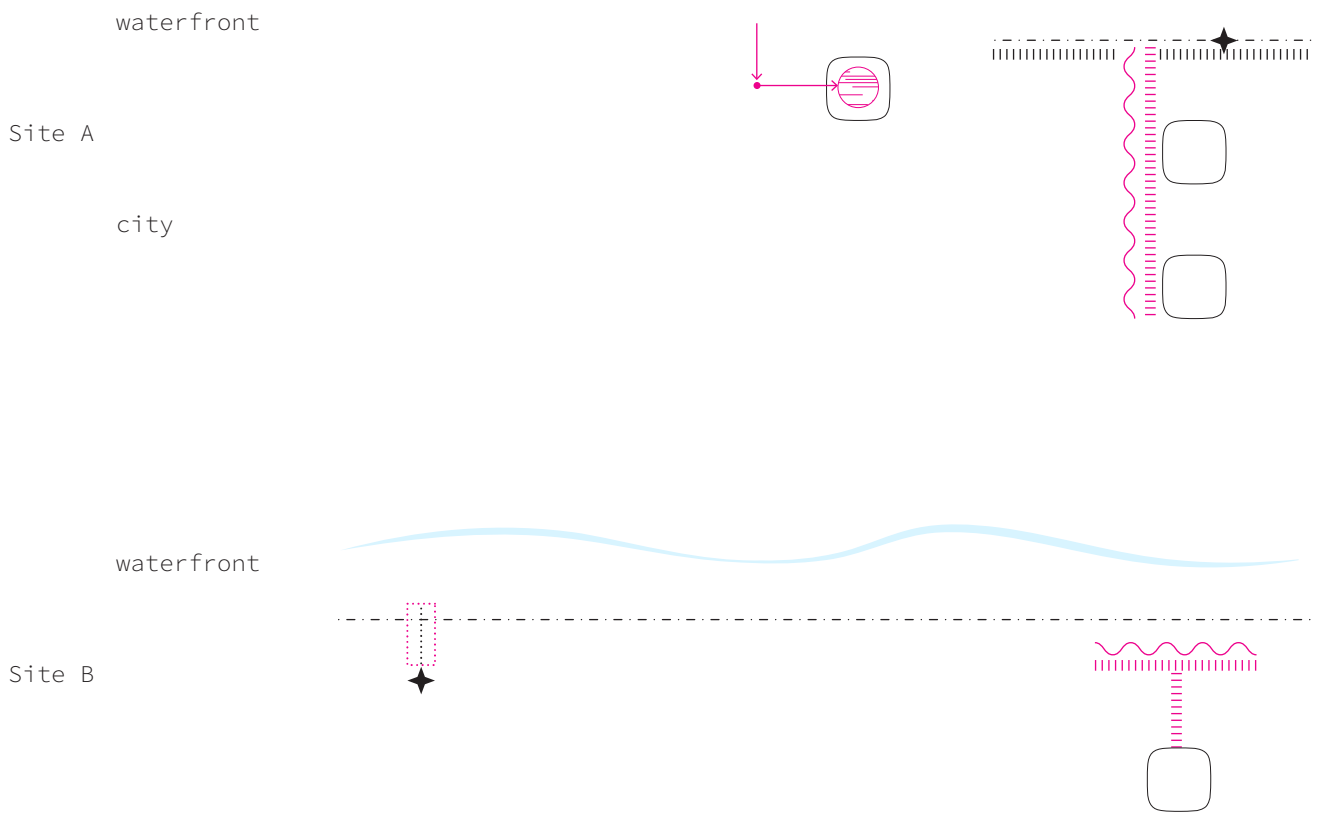
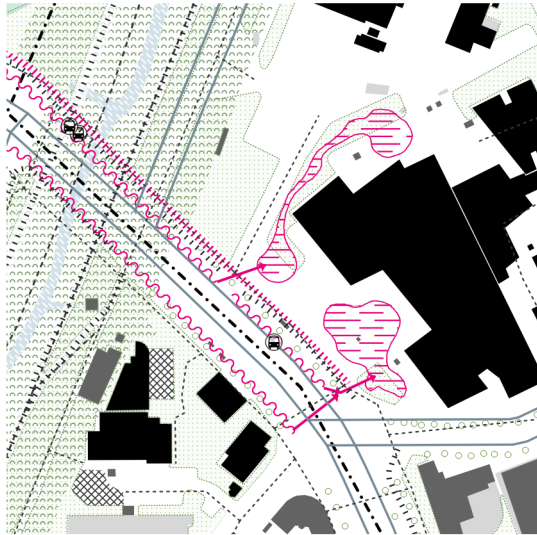
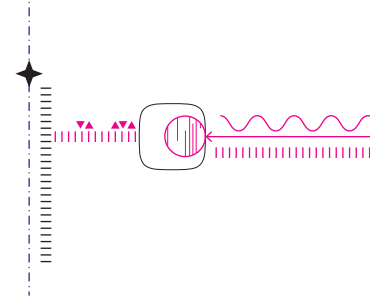


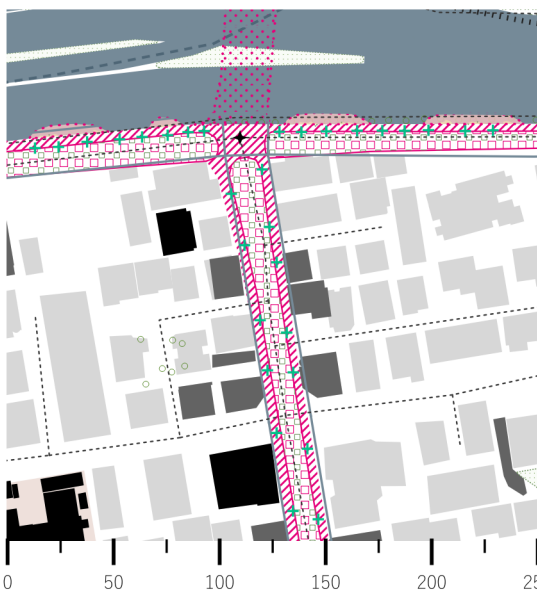
Figure 97 : Application of topological device to produce first design iteration in Hongje-3's sites



Site A



- tree (new)
- induce flow
- flood prevention
- pervious sidewalk
- traffic calming
- possible wadi
- pedestrian tunnel
- sunken alcove
- pedestrian network
- bicycle lane



Site B

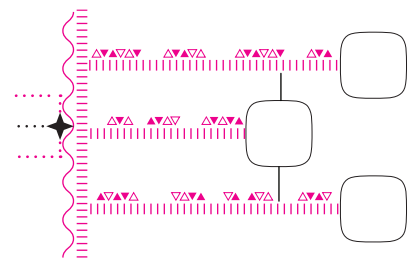
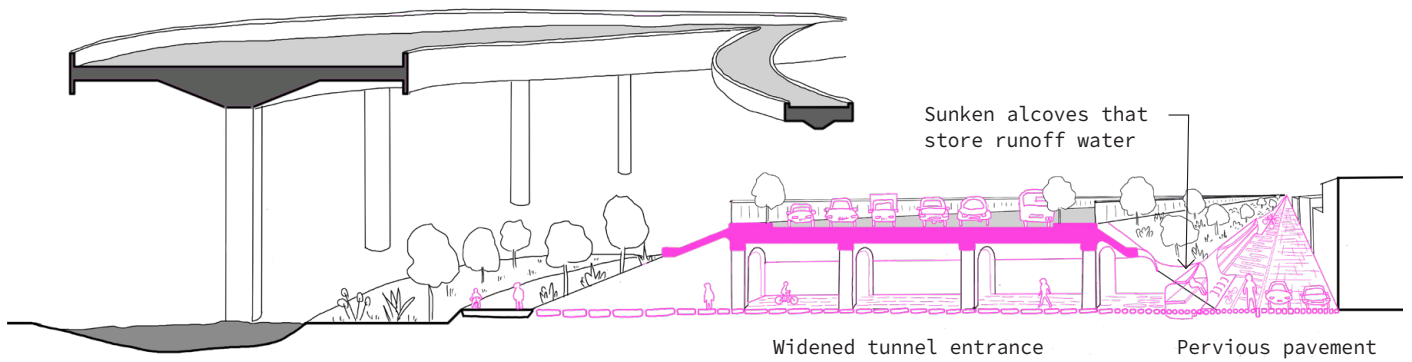
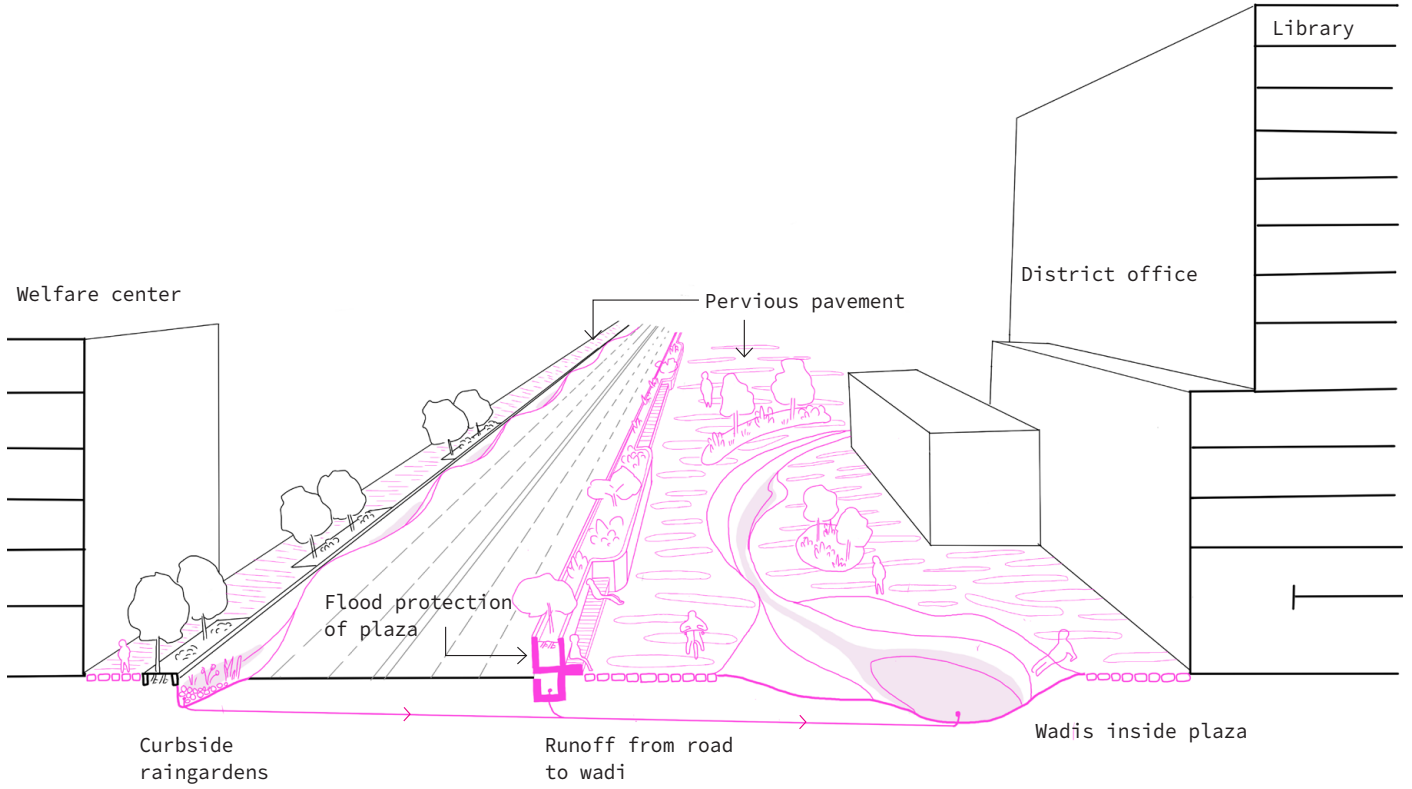


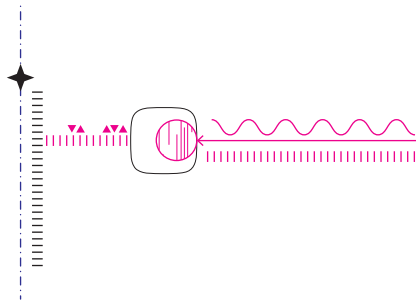
Figure 98 : First design iteration in Hongje-3's sites: plan, extracted diagram and section perspectives

Original versions of design for each site



③ Create variations - Hongje-3 Site A

original

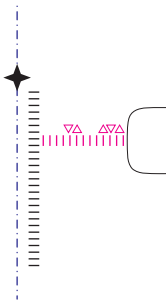


Edge - Flood protection :  
elevated X sunken X along

A bench with a drainage channel beneath located between road and the plaza prevents overflow. This channel is connected to wadis formed inside the plaza to retain runoff water from surroundings.



vari



Edge - Flood protection

A linear wadi is situated between the road and the plaza. This layer of vegetation and water provides a buffer between the wide road and the plaza. Added vegetation contributes to the comfort in the plaza.



Figure 99 : First design iteration in Hongje-3's site A varied into two other versions using abstract diagram and visualized through

variation #1



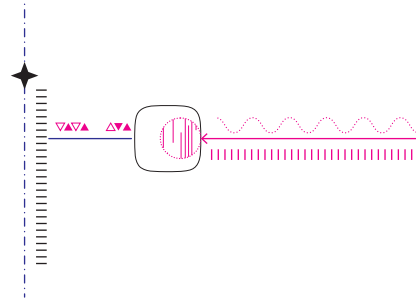
Section : sunken X along

ated between the road and  
functions as buffer between  
pedestrian friendly plaza.  
tribute to improved thermal



gh AI X-Figura

variation #2



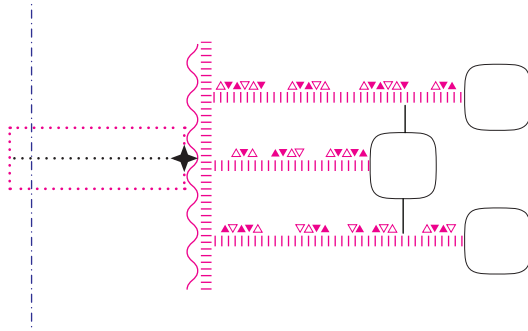
Edge - Flood protection : sunken X inward X along

The whole plaza is converted into a large water  
storage facility through partial conversion of  
its basement parking space into a storage tank.  
Drainage channel is connected to this tank and  
the perviousness of the plaza is maximized.



③ Create variations - Hongje-3 Site B

original



Waterfront - Edge: sunken X inward

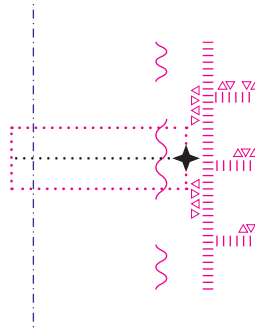
Behind - Flood protection : through X along

Behind - Heat mitigation : along X ground level

Alcoves with sunken ground level are dug into the wall along the street. These alcoves function as temporary runoff water storage in cases of severe rainfall. The dead-end street along the wall is transformed into a pedestrian friendly public space.



vari



Waterfront - E

Behind - Flood prot

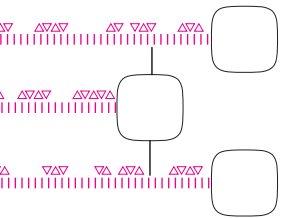
Behind - Heat mitig

The concrete wall is o that can retain water through evaporation. A the wall to prepare fo are installed between provide shadest.



Figure 100 : First design iteration in Hongje-3's site B varied into two other versions using abstract diagram and visualized through

variation #1



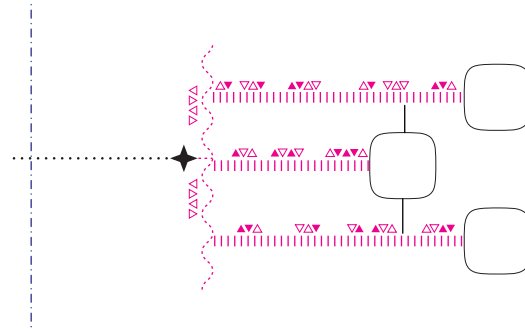
Edge: sunken X inward  
 Section : through X sunken  
 Elevation : along X elevated

Converted into a gabion wall  
 and improve thermal comfort  
 an open drain is dug along  
 for severe rainfall. Canopies  
 the wall and buildings to



High AI X-Figura

variation #2



Behind - Flood protection : elevated X along  
 Behind - Heat mitigation : along X elevated

Green canopy is cantilevered from the wall to  
 protect the street from overflow. This canopy  
 will improve thermal comfort via increased  
 evaporation and shades. Water gathered from the  
 canopy is connected to drainage pipes installed  
 along the wall.



### 3.6.3 Implementation of developed design process in Hangang 1

Table 00 :

<b>Location</b>	East of Seoul, upstream (inside Seoul)
<b>Size</b>	141.3m width X 8,969m length
<b>Climate adaptivity</b>	Type 4 Flood-safe & High thermal performance
<b>Spatial conditions</b>	Typical Hangang river park enclosed by motorway and the river

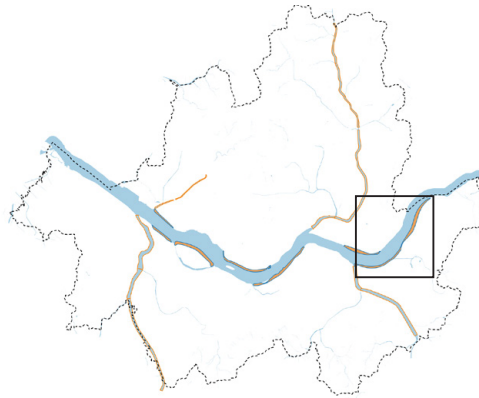


Figure 101 : Location of waterfront Hangang-1S

Hangang 1s is the most eastern and upstream segment of the river inside Seoul. It comprises two river parks: Jamsil and Gwangnaru. The western Jamsil neighbors high-rise apartments and two famous landmarks south of the river built by Lotte group (amusement park and skyscraper). The eastern Gwangnaru's local area is more mixed and includes a heritage site from the 3rd century. However, despite the landmarks that are close-by, the two parks ranked low in popularity and were more popular among local citizens (한강공원 [Hangang Park], 2026). In terms of spatial configuration, Hangang 1s is a typical river park; its border between the city is the arterial motorway that runs along the river on the south called the Olympic motorway. However, the presence of the motorway is not conspicuous inside the waterfront, thanks to the 15m height difference and ample vegetation.

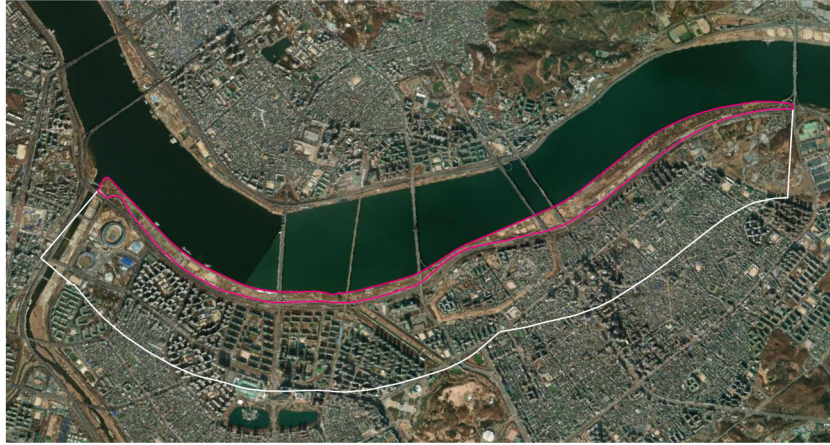


Figure 102 : Waterfront and local area boundaries of Hangang-1S



Figure 103 : Birdseyeview of waterfront Hangang-1S and its local area



Figure 104 : Relationships with adjacent infrastructures in Hangang river

① Identify effective design locations : Hangang-1S

Overlap three scenarios: heatwaves, flash floods, and moderate climate

Heat wave scenario

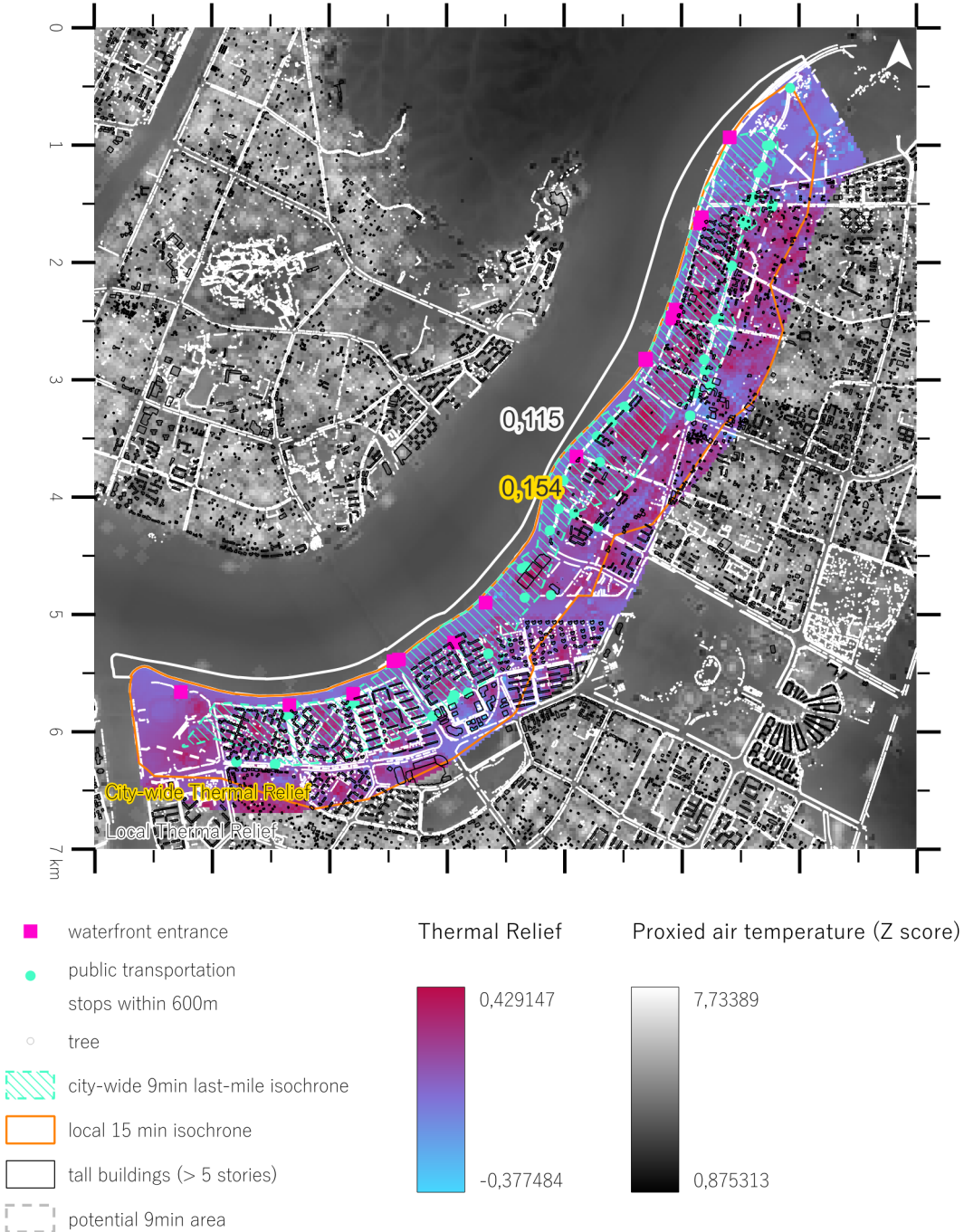


Figure 105 : Analysis of Hangang-1S's climate adaptive performances against heatwaves

High thermal relief city-wide but low value in local scale indicates that the river park's local area is cooler than other parts of the city. This signifies that demand to visit the waterfronts during heatwaves will be higher for non-locals. Hangang 1s is the only waterfront where thermal refuge accessibility was above standard in both scales. These high performances were result of even distribution of bus stops and entrances from west to east connected by an efficient gridded network.

### Flash flood scenario

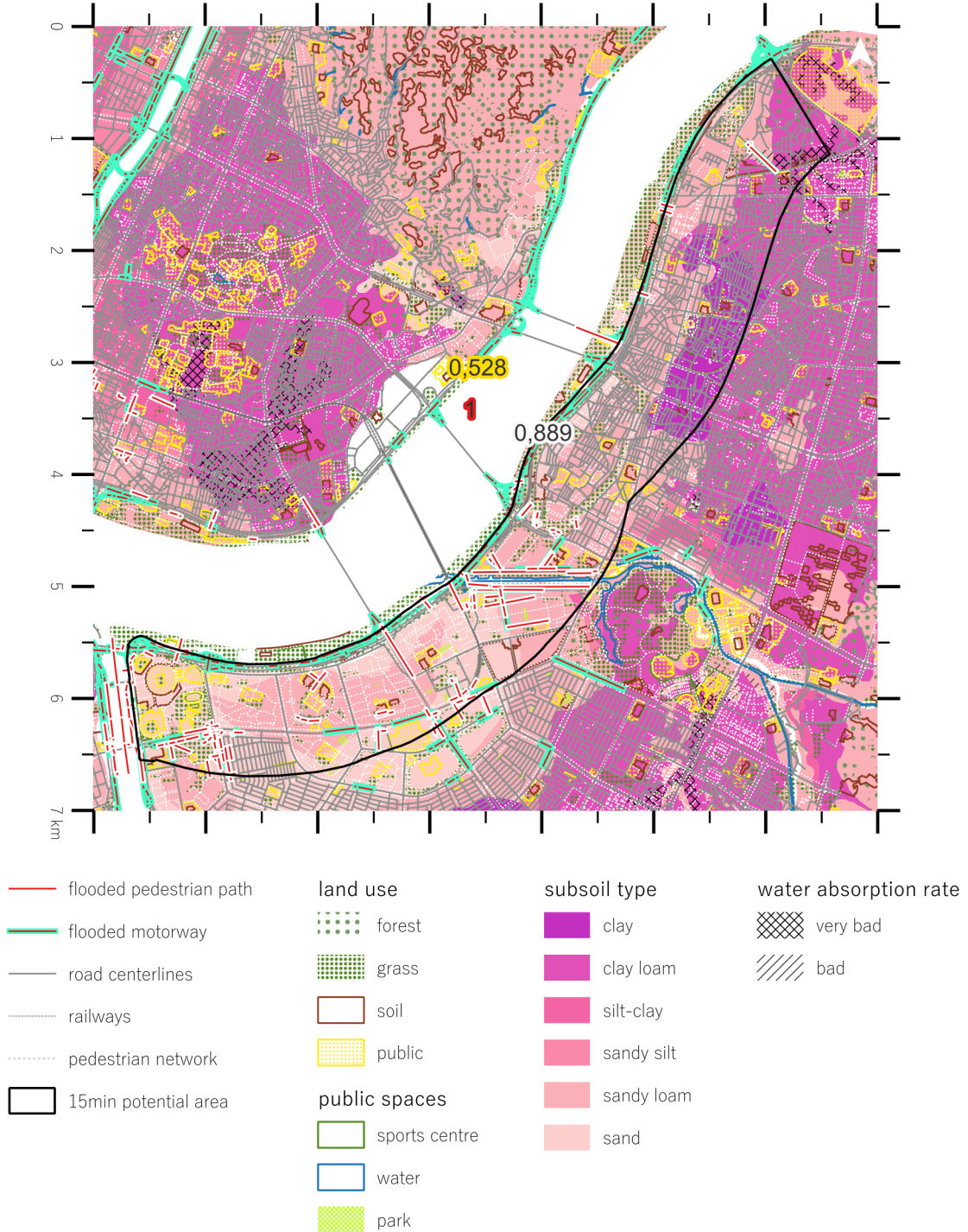


Figure 106 : Analysis of Hangang-1S's climate adaptive performances against flash floods

Despite low possibility of overflow, Hangang 1s was analyzed to cause more disruption on the city-wide automobile network than its local pedestrian network. In city-scale, the challenge would be to protect the main arterial motorways from inundation. Inundated pedestrian paths were concentrated near the tributaries and the two parks in the west that neighbor the low-rise dense area. Fortunately, the waterfront and its surrounding area have sufficient open spaces that can be used to temporarily store runoff water from important roads.

Moderate climate

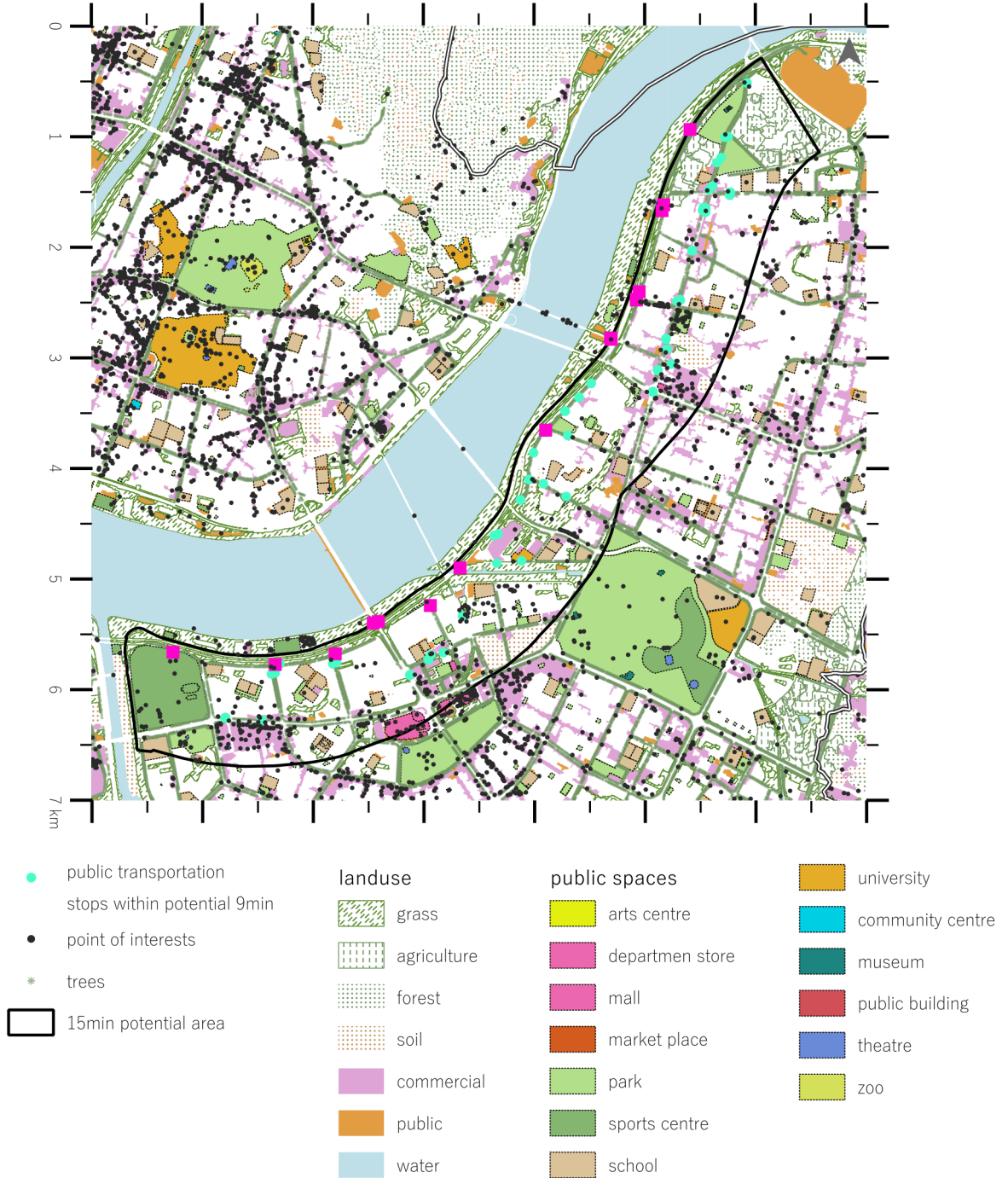
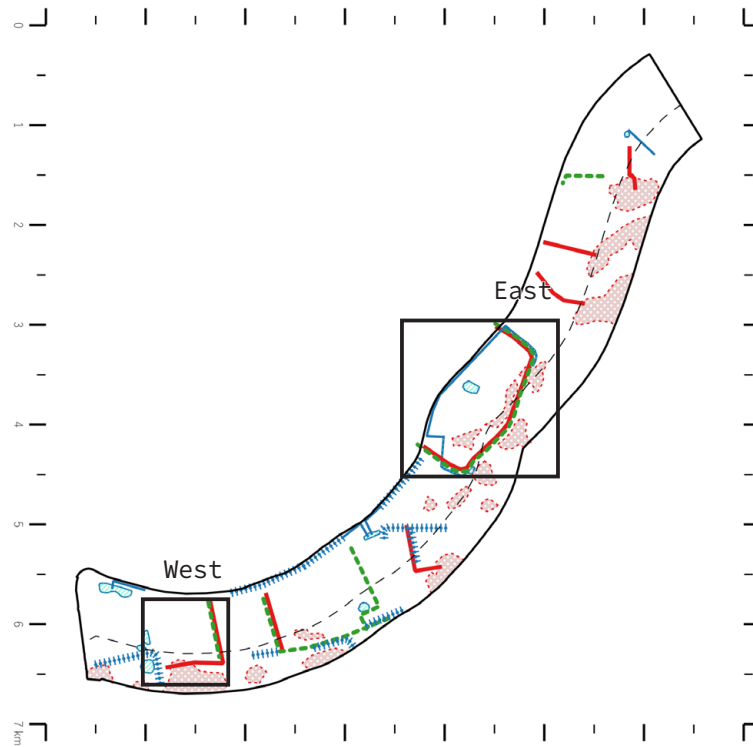
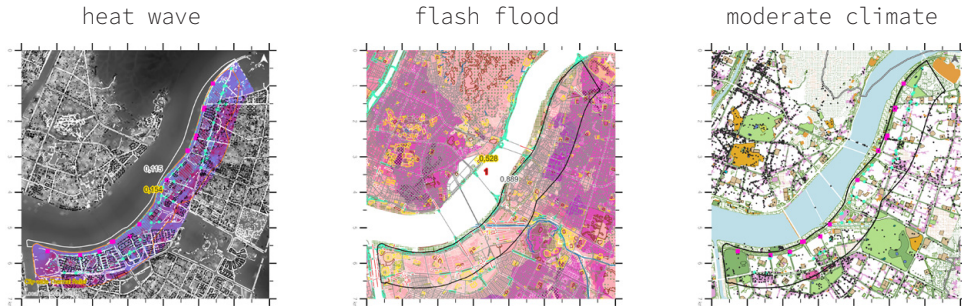


Figure 107 : Analysis of Hangang-1S's pedestrian connectivity during moderate climate

The pedestrian network in the western half of the local area is more than decent. Vegetated paths link the waterfront with key public spaces which are also ample with green open spaces. However, the network becomes fragmented as one moves eastward. Although the soil wall from the 3rd century, shown as a green oval ring in the eastern part, is planned to be restored, its potential to boost pedestrian quality of daily life has yet been unexplored.

### Intervention locations



- induce flow
- ||||| flood resistance
- ▨ possible wadi
- thermal relief access
- ▨ hot area without waterfront access
- 15min potential area
- 9min potential area

Figure 108 : Hangang-1S's conclusion map overlapping performances under three climatic scenarios

② Select spatial strategies : Hongje-3

Use climate adaptivity analysis & classification results



Figure 109 : Butterfly chart of Hangang-1S's comprehensive climate adaptivity

*Spatial elements*

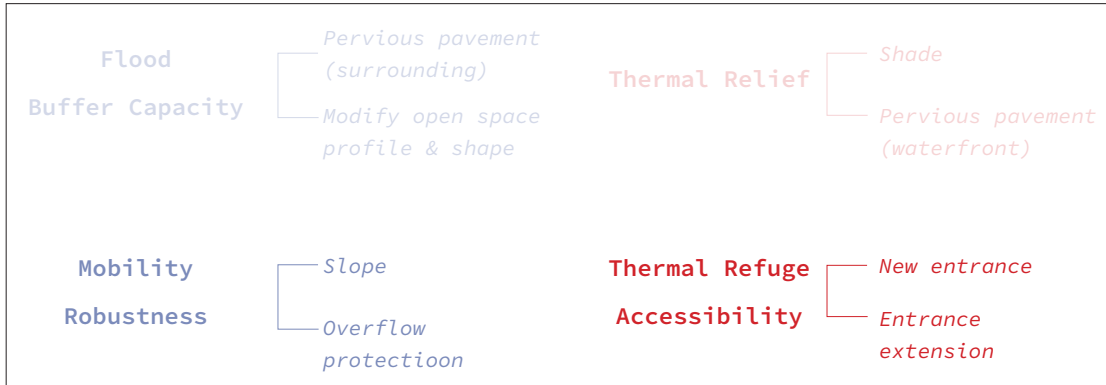


Figure 110 : Spatial elements that can be leveraged for Hangang-1S

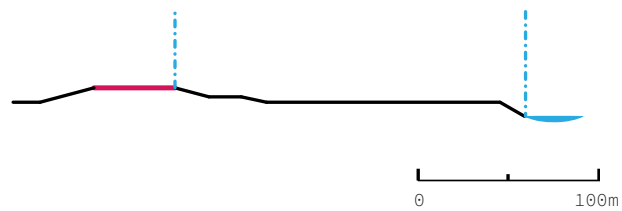


Figure 111 : Typical cross-section of Hangang river

Site conditions & applicable range of elements

Tunnel entrance



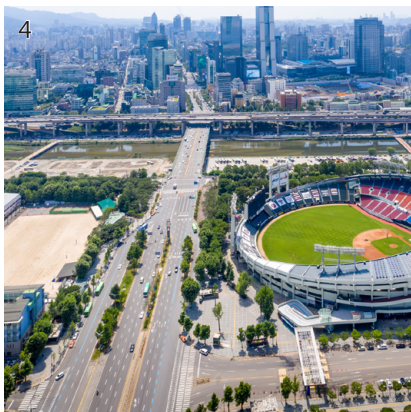
Road towards water along heritage



Wide roads between apartments



Main roads between public spaces



*Extend entrances*

*New entrances*

*Slope*

*Overflow Protection*

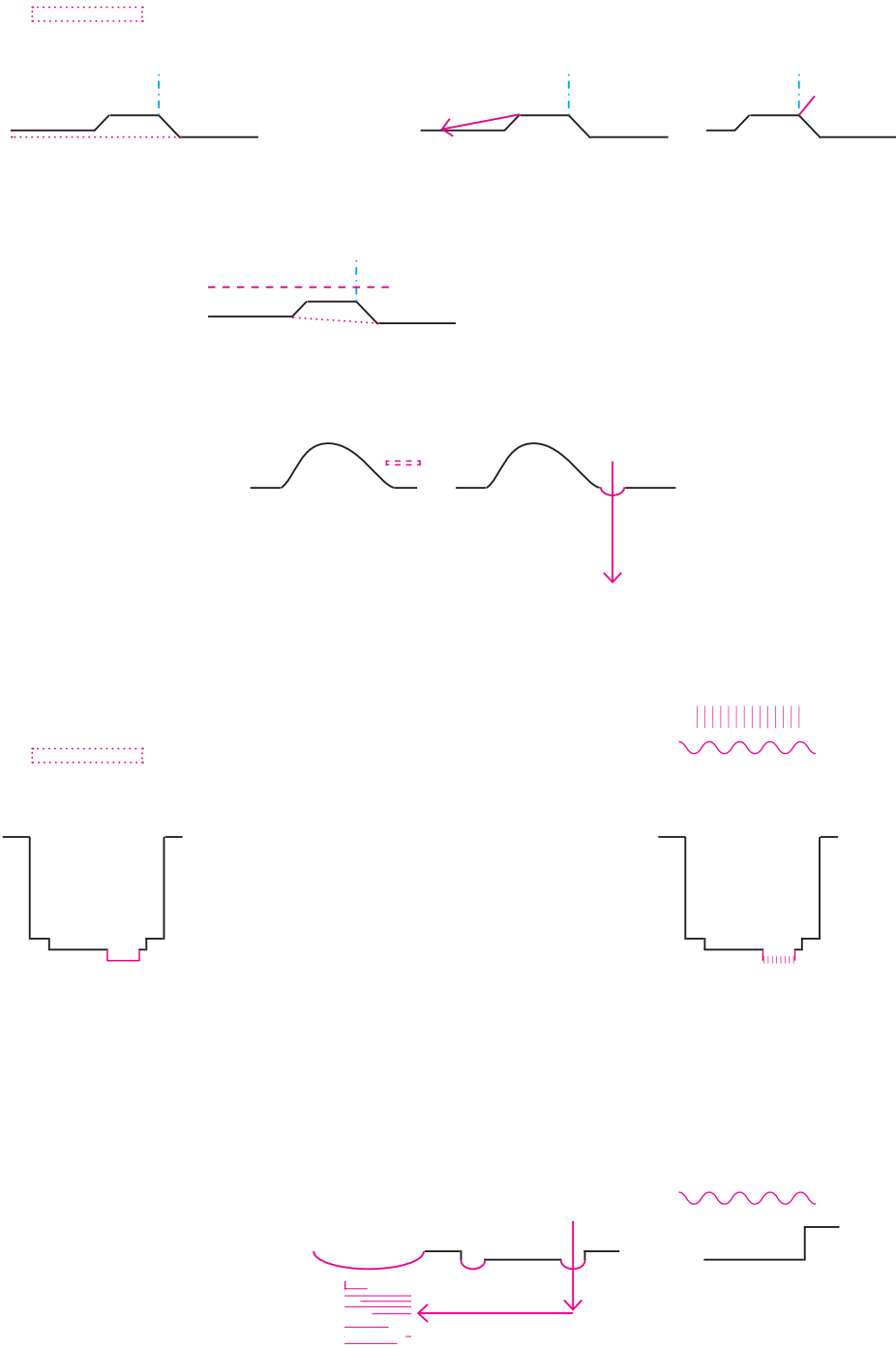


Figure 112 : Range of spatial elements applicable in typical site conditions of Hangang-1S

### ③ Spatialize elements and create variations : Hangang-1S

#### Site conditions & specific locations

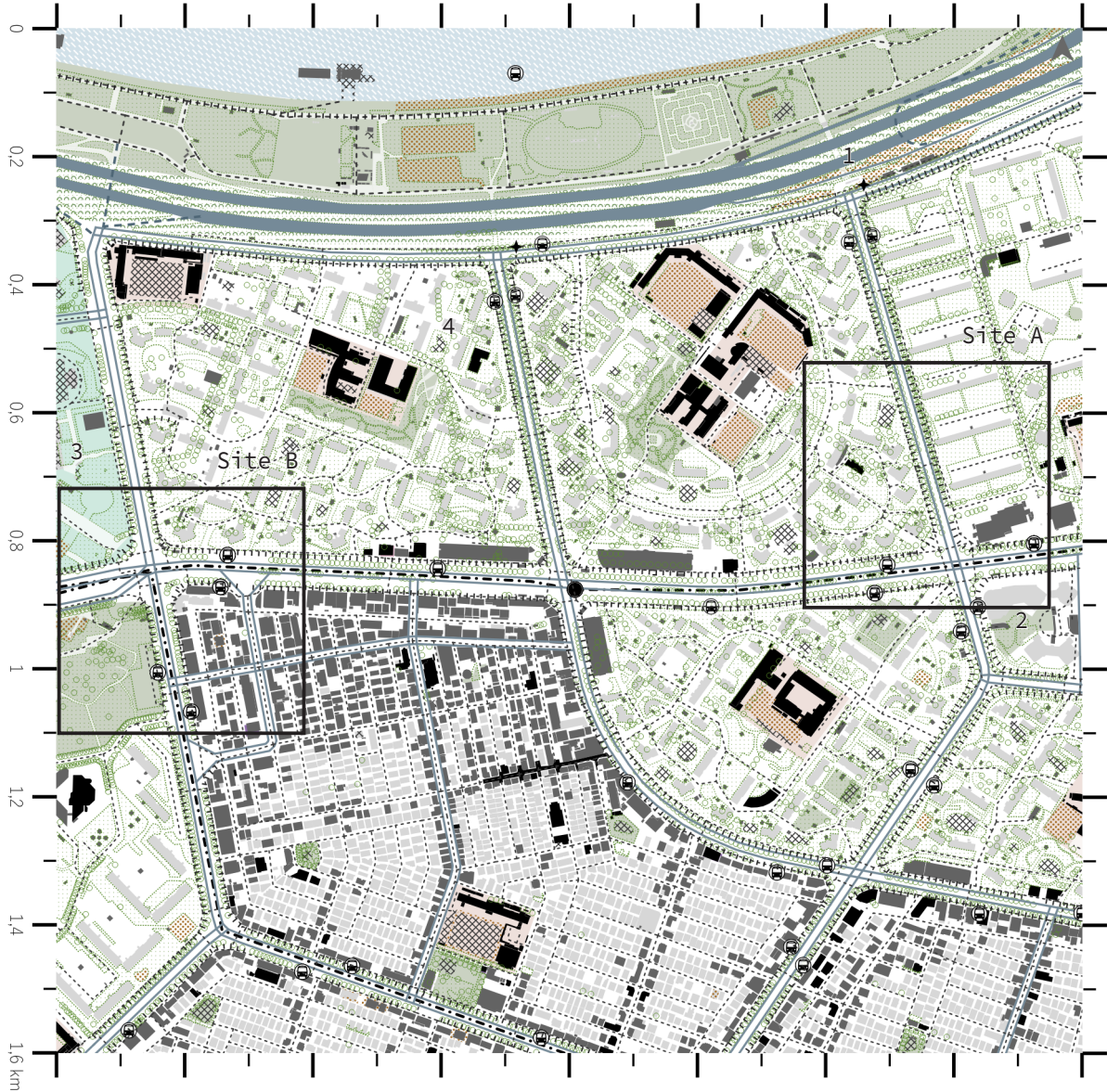



















Figure 113 : Plan of Hangang-1S North

Majority of the western part, near Jamsil river park, is comprised of high-rise apartment complexes. These enclaves which includes many public facilities within including schools, have manifested conflicts with other neighboring communities regarding the access of these public services (Baek, 2025). Under this context, improved accessibility to the sports complex and the large neighborhood park in the west from the low-rise mix-use neighborhood provide key to smoother integration. The two landmarks -amusement park and skyscraper- currently lack spatial connection with the waterfront. The route to the waterfront from these locations are extensive semi-private wide roads enclosed by the high-rise apartments to reach the waterfronts. This spatial configuration is typical in Hangang river parks whose adjacent area often consists of luxurious apartment complexes referred as the “Hangang belt”.

○ tree	 waterfront adjacent roads	<b>land use</b>	<b>point of interest</b>
✦ entrances	 pedestrian area	 commercial	 park
- - - - pedestrian network	 water	 public	 sports centre
● metro stop	 bldgs	 soil	 school
 bus stop		 leisure	 library
- - - - overpass		 vegetation	 community centre
 autoway			 waterfront green
- - - - metro lines			

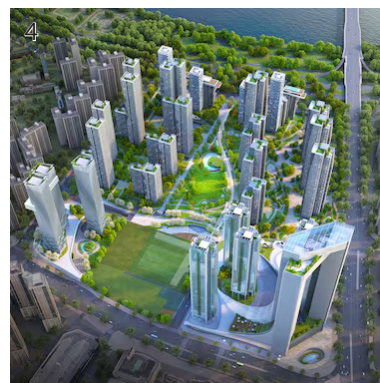


Figure 114 : Points of interests and site conditions of Hangang-1S West



Site A

The six-lane road between apartment enclaves is almost exclusively used by the residents. These apartment complexes are elevated from the road level by 2-3 meters which has the effect of efficiently limiting access and delineating their borders. One way to improve the walkability to the waterfronts is to provide a cozy sunken path separated from both the car-centric roads and high-rise complexes. This sunken space lengthens the waterfront experience towards the center, thus equal to extending the waterfront entrance.



Site B

The existing tunnel between the sports complex with the neighborhood park must be widened to make the connection more explicit and populated. This connection is integral to the enhancement of walkability of routes from the low-rise neighborhood to the waterfront, which begins from the alleys inside these regions. Coincidentally, this site also consists of paths that will be inundated in case of severe rainfalls. Therefore, the widened tunnel can also function as a wadi in this scenario.

Figure 115 : Spatial elements applied in sites of Hangang-1S West

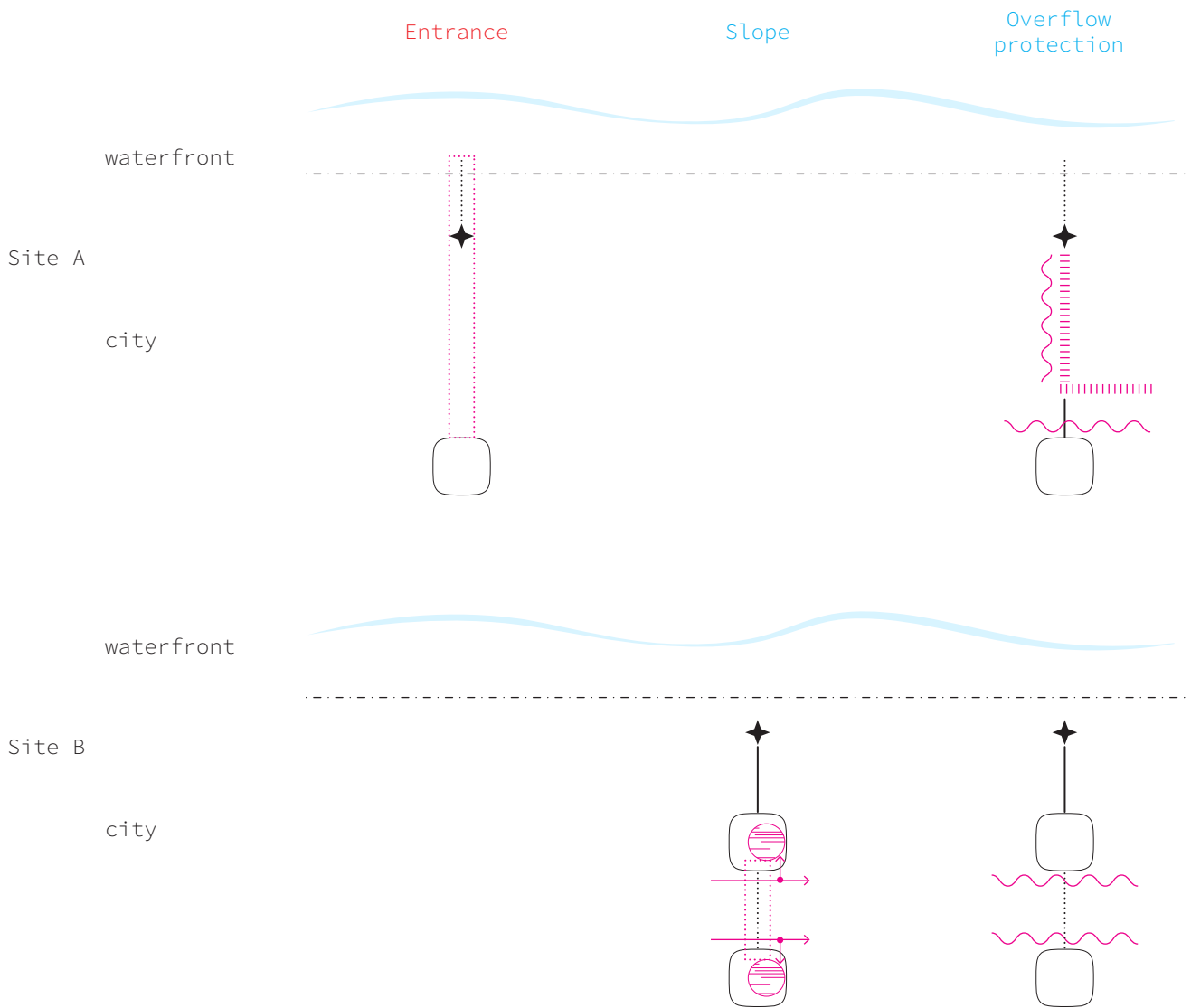
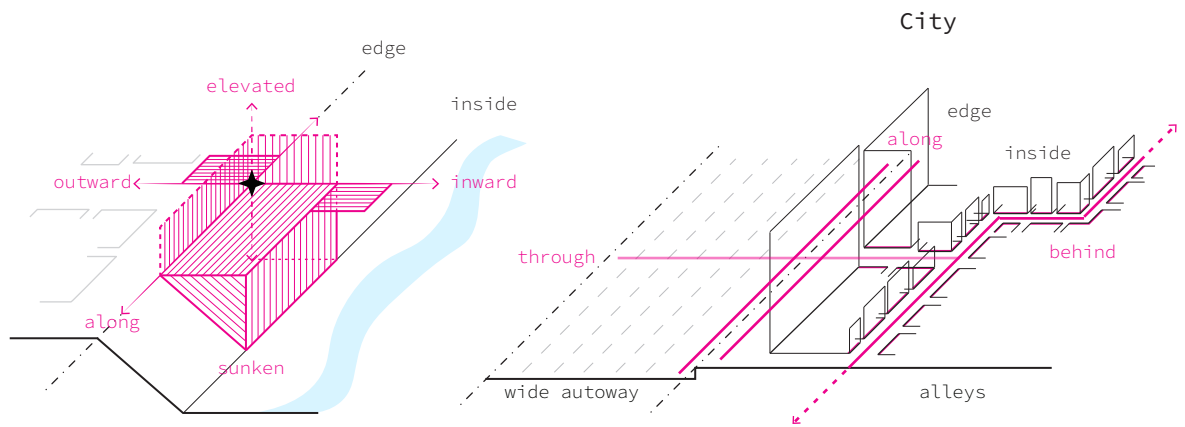
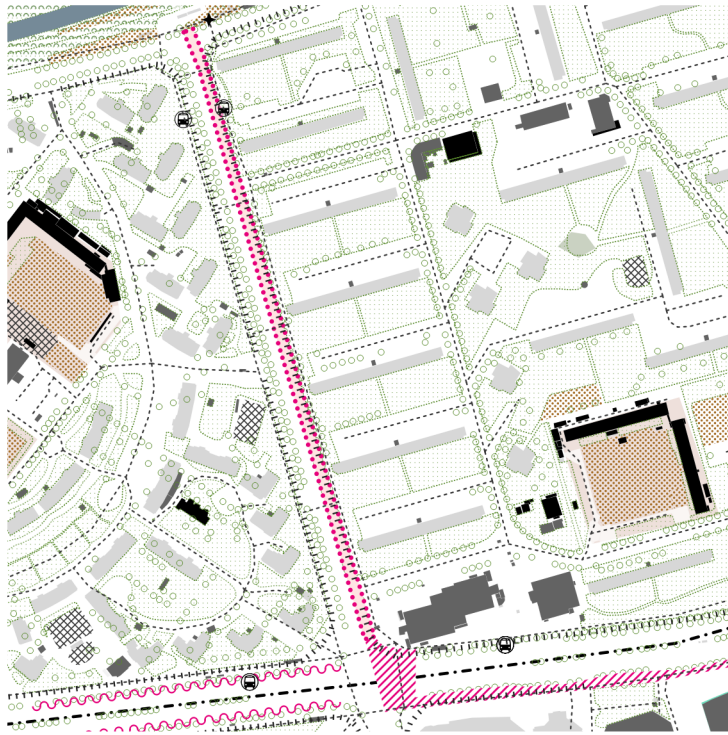
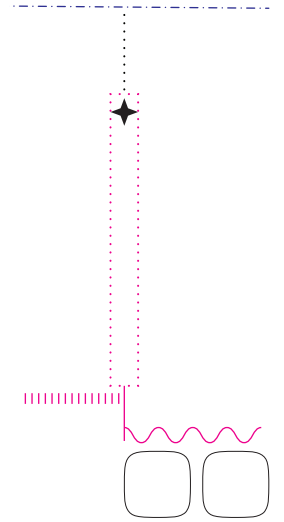


Figure 116 : Application of topological device to produce first design iteration in Hangang-1S West's sites

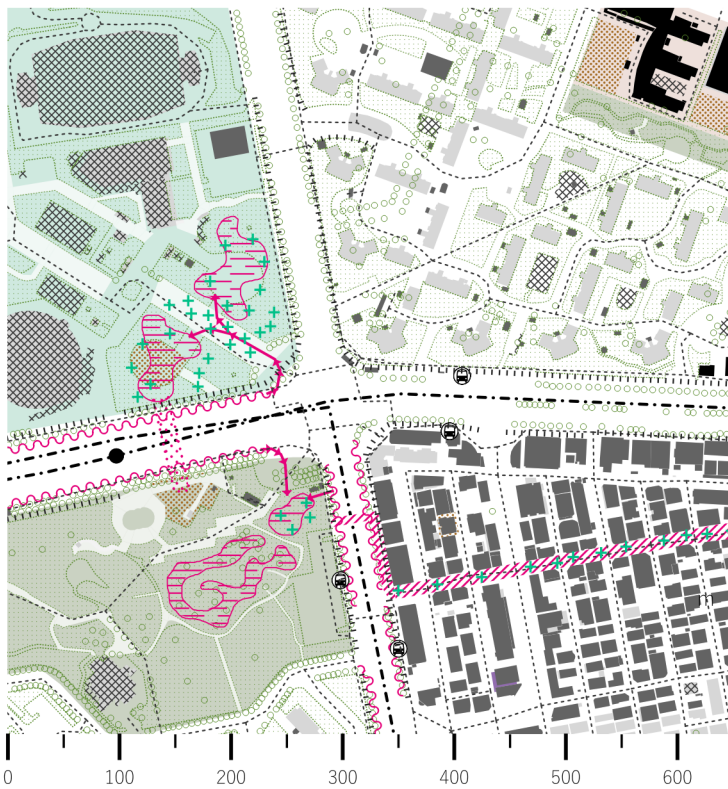


- + natural shade
- ..... bicycle track
- induce flow
- ~~~~~ flood resistance
- //// pervious sidewalk
- ▣ traffic calming

Site A



- ▣ pedestrian tunnel
- ▣ wadi
- ▣ sunken pedestrian path



Site B

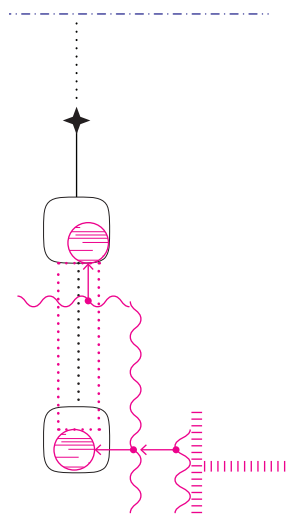
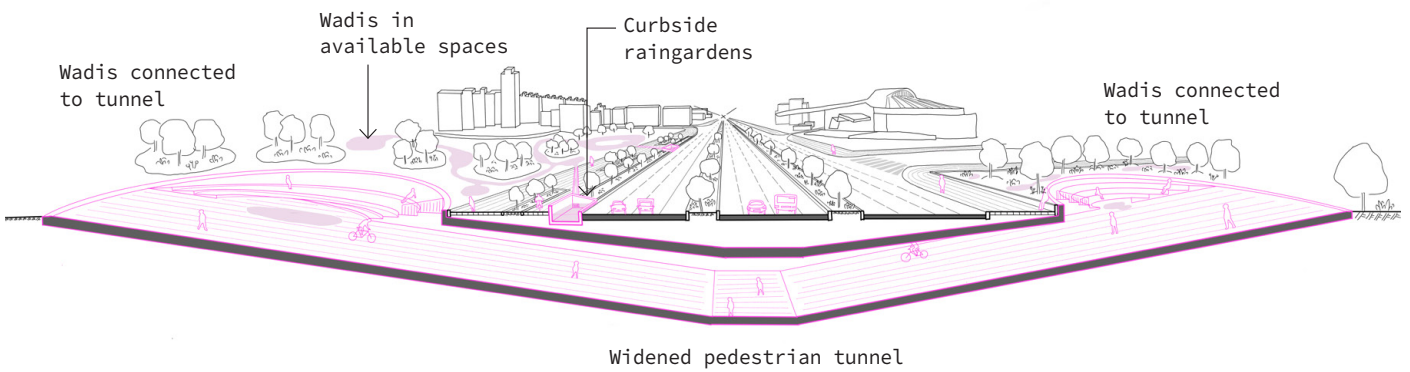
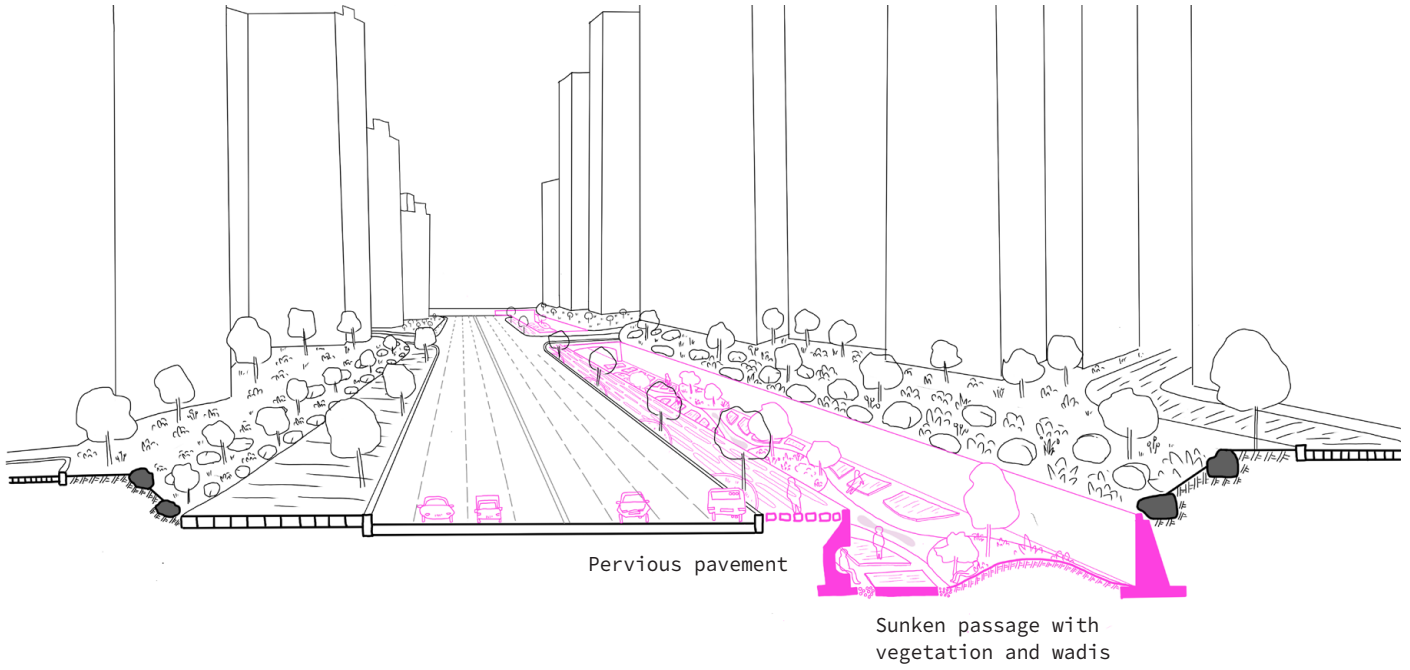


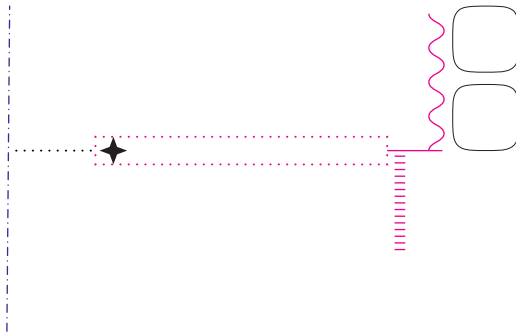
Figure 117 : First design iteration in Hangang-1S West's sites: plan, extracted diagram and section perspectives

Original versions of design for each site



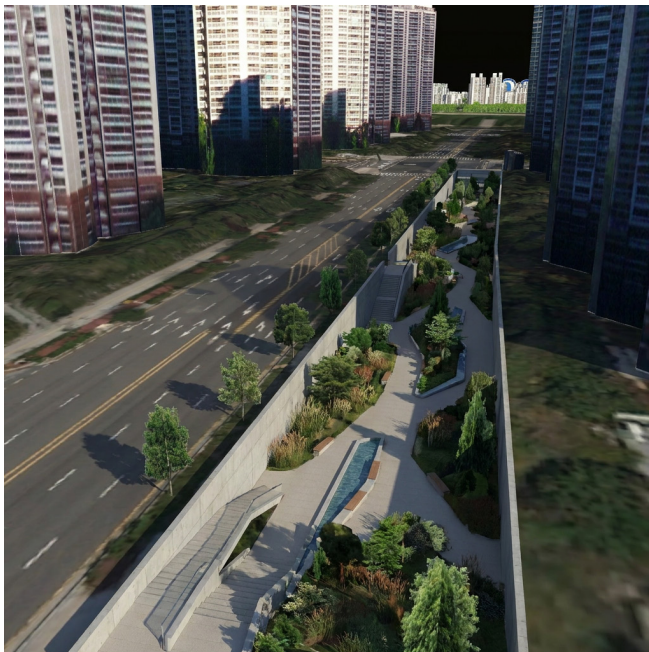
③ Create variations - Hangang-1S West Site A

original

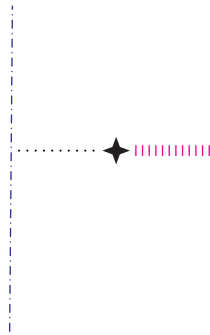


Waterfront - Edge: sunken X along

Part of the wide sidewalk and a car lane is transformed into a sunken passage. This enclosed passage has the effect of extending the waterfront. It also creates delineates an additional spatial layer for pedestrians who walk through the semi-private, car-centric road.



vari



Waterfront - Edge

Vegetation is added and transformed into pervious ones instead. The purpose is to give character and softens the edge between the wide sidewalk and the apartments on top of p

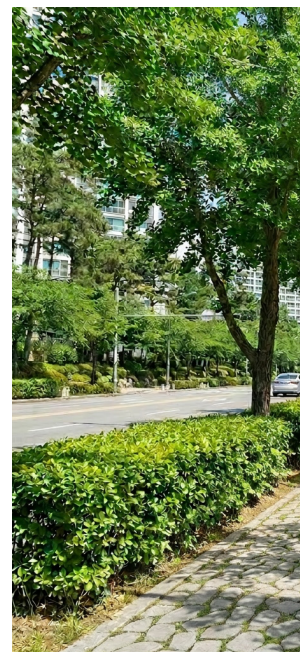
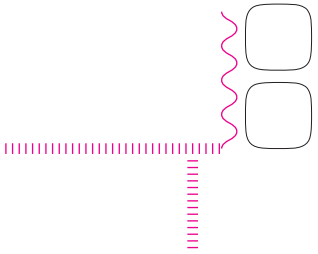


Figure 119 : First design iteration in Hangang-1S West's site B varied into two other versions using abstract diagram and visualization

variation #1



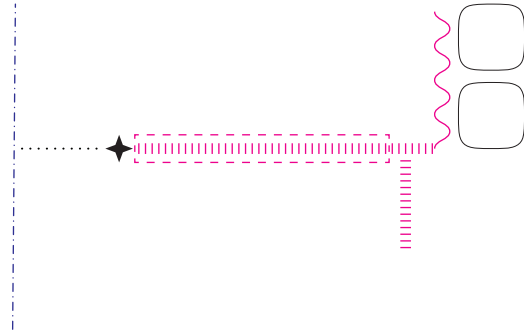
Waterfront - Edge: ground level X along

and pavement is converted  
side the sidewalk. The  
character to the sidewalk that  
roads and the high-rise  
buildings.



Created through AI X-Figura

variation #2



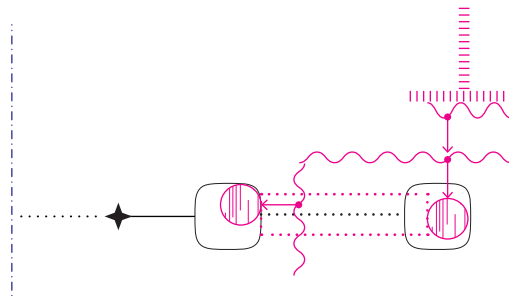
Waterfront - Edge: elevated X along

Canopies are installed in the sidewalk to make  
the journey to the waterfronts more comfortable.  
The canopy is also effective for the division  
of the sidewalk between pedestrians and slow  
mobility.



③ Create variations - Hangang-1S West Site B

original

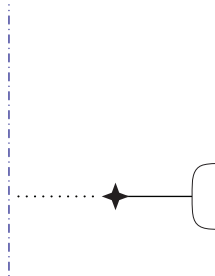


City - Edge: sunken X through X ground level

The existing tunnel that runs below the wide road is widened into a ramp that is connected to wadis. Overflow from the road is protected through wide drain channels that are linked to wadis.



vari



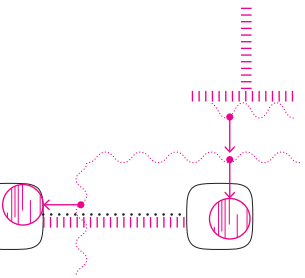
City - Edge: gr

In this version, the o facilitated via instal with pervious pavement reduced into a network space.



Figure 118 : First design iteration in Hangang-1S West's site A varied into two other versions using abstract diagram and visualization

variation #1



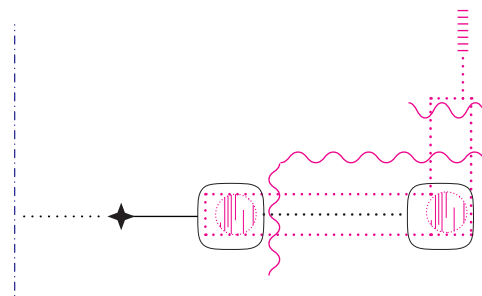
ground level X through

crossing of the wide road is  
 relation of a wide crossroad  
 . The size of wadis are  
 between trees in the green



ed through AI X-Figura

variation #2



City - Edge: sunken X through

This version is a more extreme version of the  
 original iteration. Instead of wadis, a sunken  
 network is installed below the road level and  
 extends towards the low-rise dense neighborhood  
 to increase walkability.



### ③ Spatialize elements and create variations

#### Site conditions & specific locations

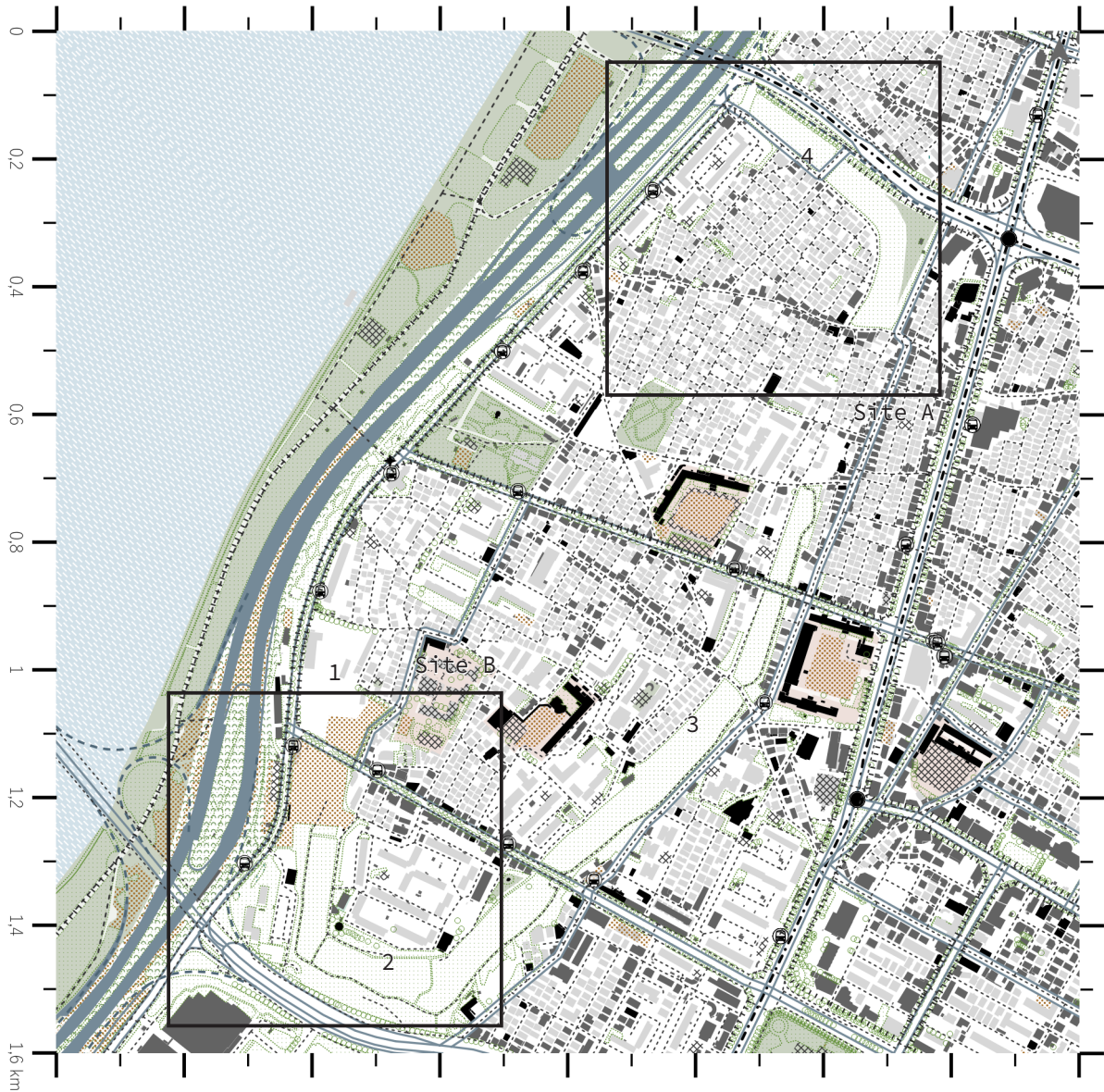


Figure 120 : Plan of Hangang-1S East

The eastern half of Hangang 1s's local area is much more mix-used, as shown in the variation of urban fabric shown in Figure 120. The ancient soil wall has potential to boost integration of different communities that coexist in these environments thanks to its linear configuration. As the wall becomes fully restored, axes that penetrate through the ring will lose centrality through fragmentation. Instead, pedestrian paths along the ring will be fortified. The wall is believed to have accompanied a narrow moat around, which will serve as a natural wadi if restored. Its proximity to the motorways suggest overflow of these arterial roads can be guided to the green ring.


















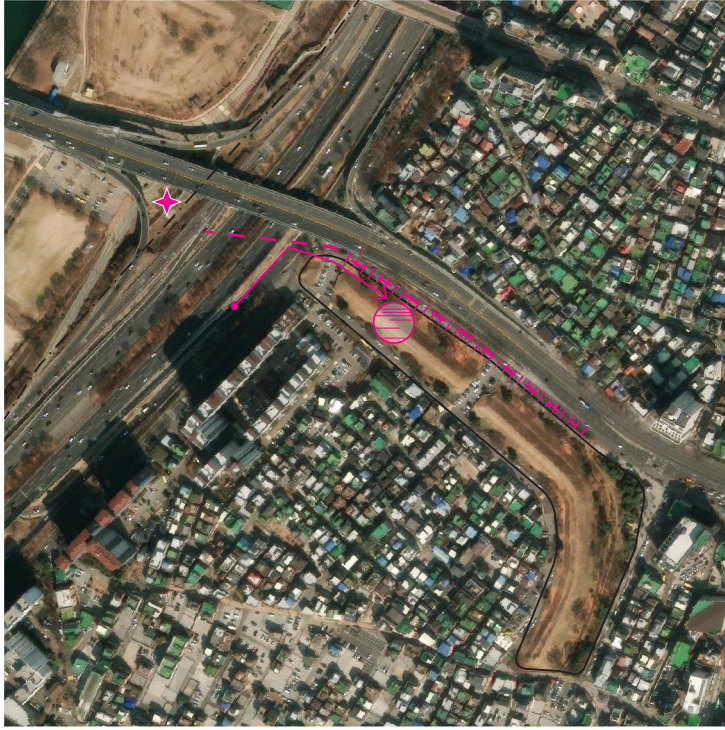
○ tree	 waterfront adjacent roads	<b>land use</b>	<b>point of interest</b>
✦ entrances	 pedestrian area	 agricultural	 park
----- pedestrian network	 bldgs	 commercial	 sports centre
● metro stop	 waterfront green	 public	 school
 bus stop	 water	 soil	 library
--- overpass		 leisure	 community centre
— autoway		 vegetation	
- - - - metro lines			



Figure 121 : Points of interests and site conditions of Hangang-1S East



Site A

The northern end of the soil wall runs parallel to a six-lane road that is sloped upwards to reach the level of Cheonho bridge that crosses the Hangang river. Although the typical way to enter riverfronts is through a tunnel, the overlapping roads beneath the bridge increases the difficulty of implementing this method. An alternative way of entry would be through elevated walkways. This allows the narrow street between the wall and the lifted road to become an extension of the green ring shaded by the structure.



Site B

The southern end is under similar circumstances, this time with the Olympic bridge. However, in this case, the ring is less proximate with the wide road buffered by a small, vegetated area. Instead, it is closer to the motorway due to its extended tail that bends towards northeast. An elevated walkway can also be implemented here instead of a tunnel, which will provide a unique view of the waterfront outlined by intertwining infrastructures. This walkway also opens possibility of utilizing small leftover space between motorways for public use by allowing pedestrian access.

Figure 122 : Spatial elements applied in sites of Hangang-1S East

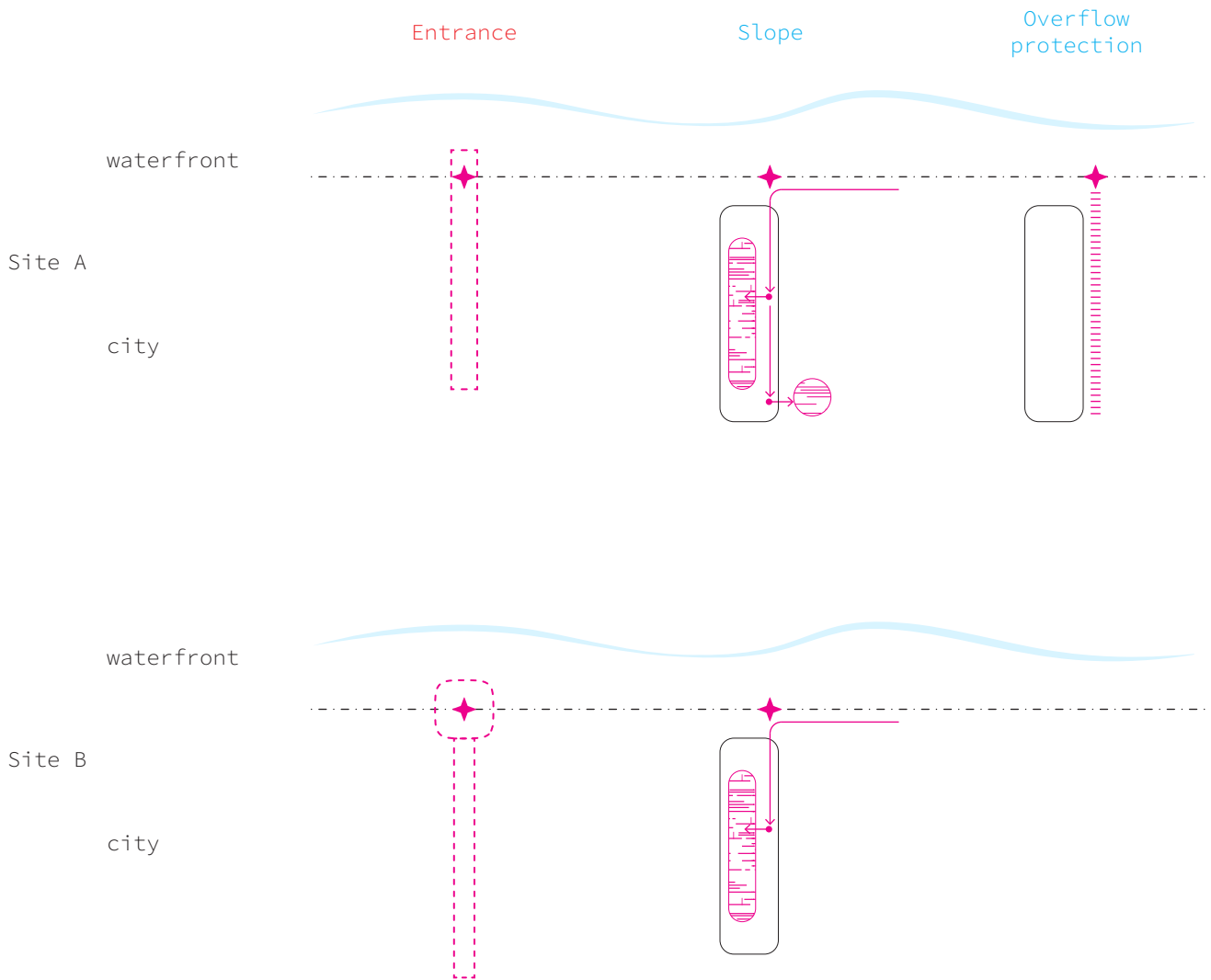
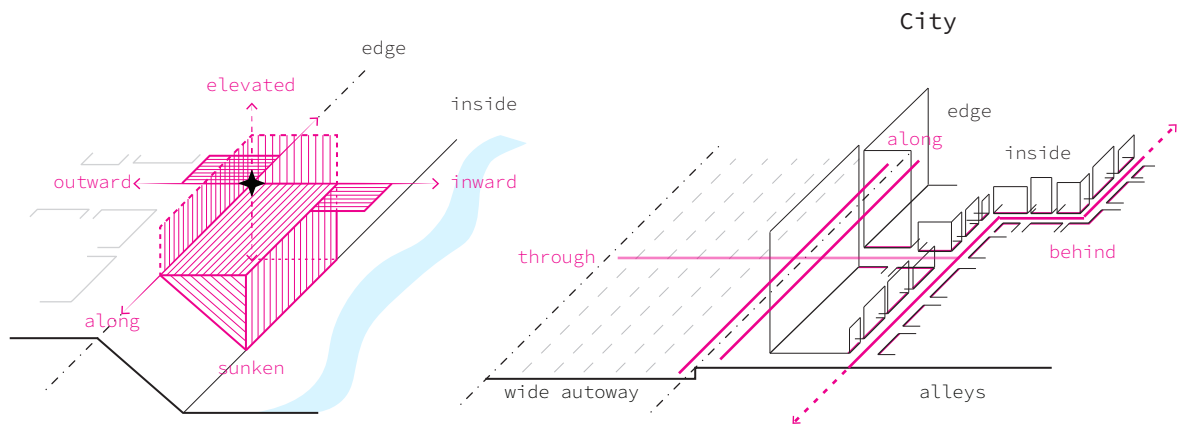
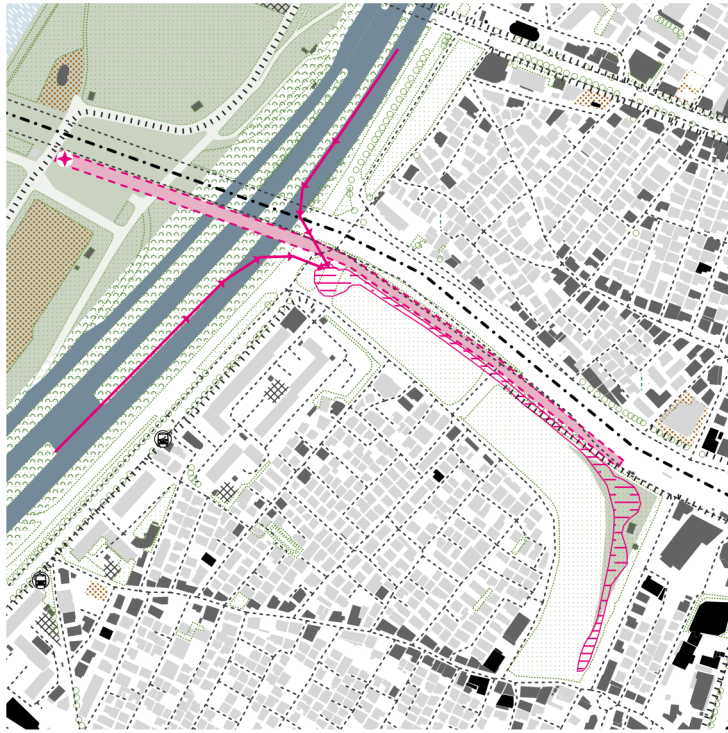
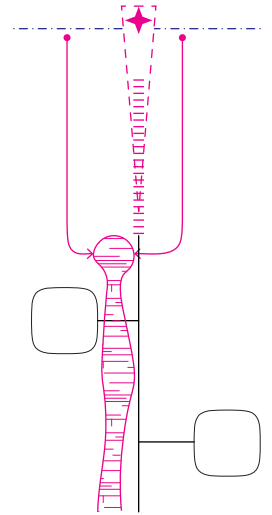


Figure 123 : Application of topological device to produce first design iteration in Hangang-1S East's sites

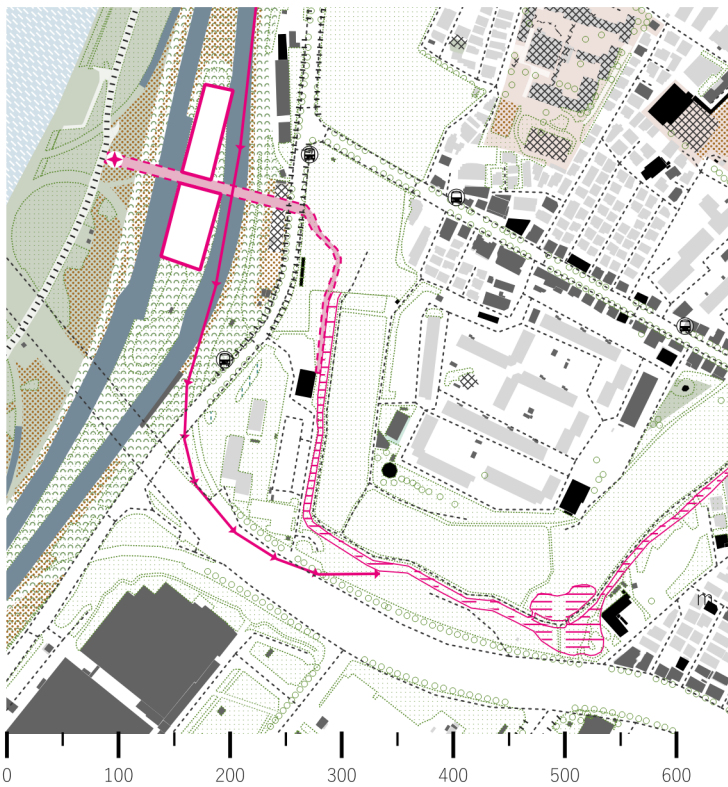


- ◆ new entrance
- ◆ natural shade
- ..... bicycle track
- slope
- ~~~~~ water
- - - - metro lines

Site A



- building
- ▨ elevated park
- ~~~~~ wadi



Site B

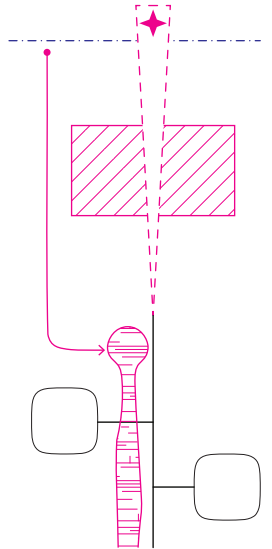
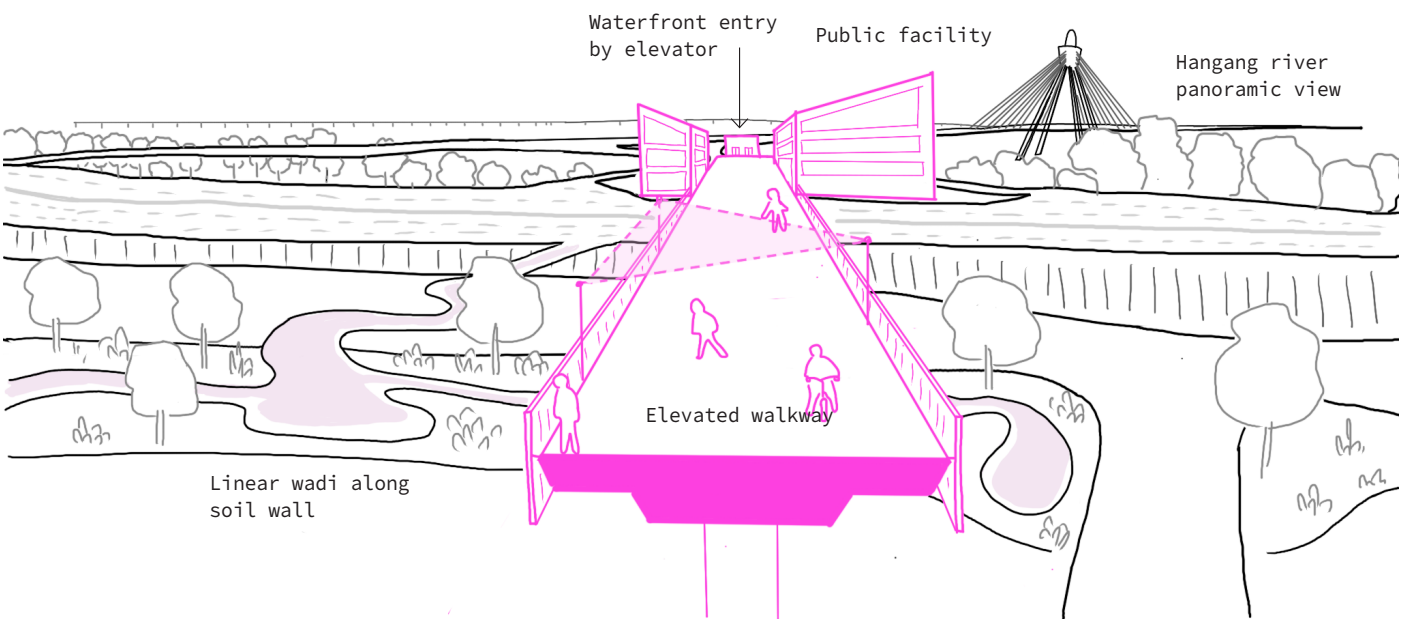
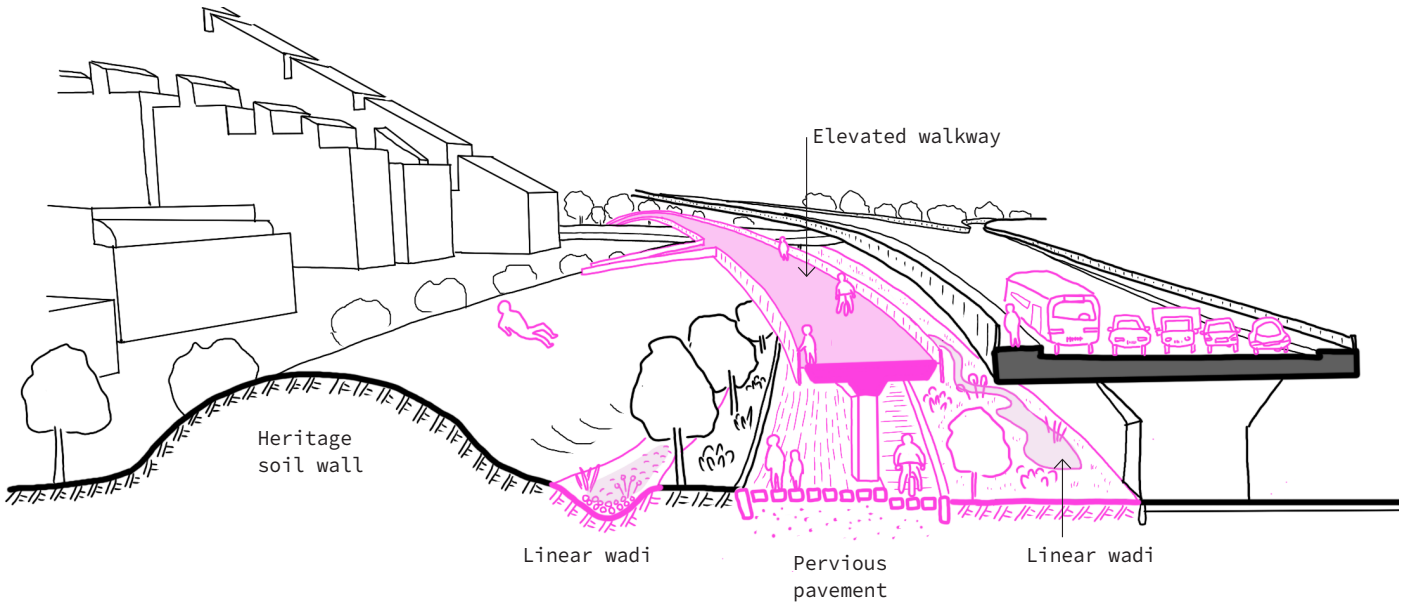


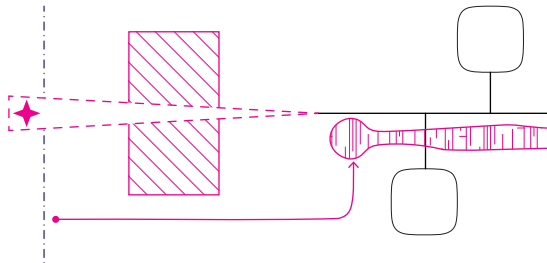
Figure 124 : First design iteration in Hangang-1S East's sites: plan, extracted diagram and section perspectives

Original versions of design for each site



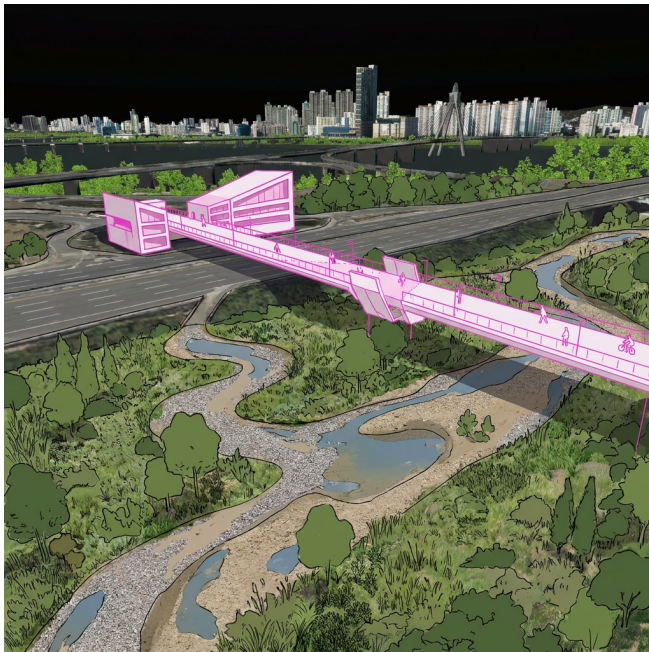
③ Create variations - Hangang-1S East Site A

original

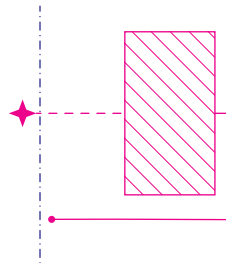


Edge: elevated X inward

Path that ran along the soil wall gradually elevates into a level that allows the walkway to cross over the motorways. The walkway gives access to public facilities that is built in the left-over space between the motorways.



var



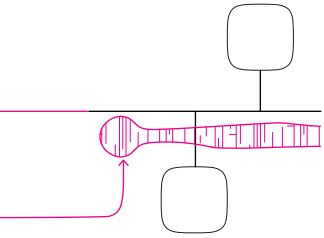
Edge: ground

Ground-level path penetrates... which motorways are built... to the basement of public... the left-over space from... elevated walkway gives



Figure 125 : First design iteration in Hangang-1S East's site A varied into two other versions using abstract diagram and visualization

variation #1



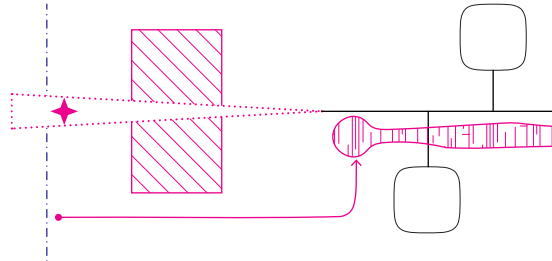
and level X inward

penetrates through the dike on  
 built on. This path leads  
 public facilities built in  
 from whose upper floors an  
 access to the waterfront.



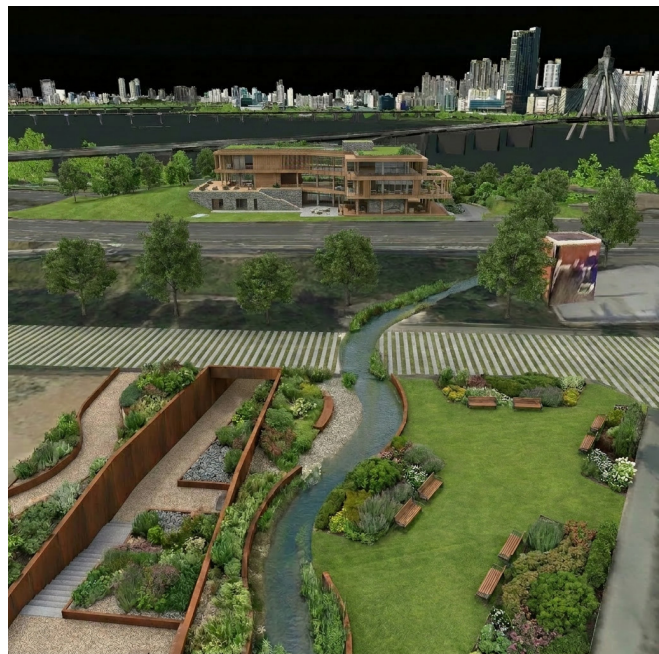
ed through AI X-Figura

variation #2



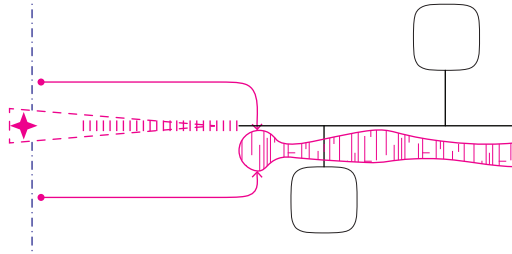
Edge: sunken X inward

A sunken path connects the green ring directly  
 to the waterfront. Weakened connection to the  
 new public facilities can be compensated through  
 installation of sunken atriums which will also  
 provide sunlight to the passage.



③ Create variations - Hangang-1S East Site A

original

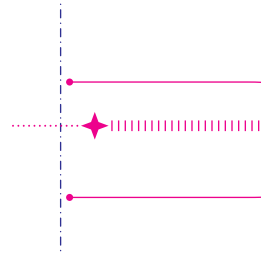


Edge: elevated X inward

An elevated walkway is placed between the overpass and the soil wall, and crosses over the motorway to arrive at the waterfront. Wadis are dug out along the soil wall to store overflow from the motorways.



var



Edge: ground

A pervious path runs between the soil wall and the motorway, which motorways are placed with linear wadis. This is a full restoration of the

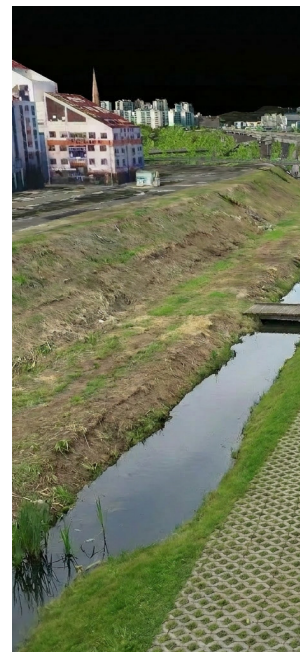
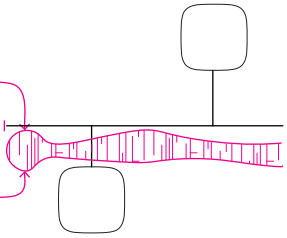


Figure 125 : First design iteration in Hangang-1S East's site B varied into two other versions using abstract diagram and visualization

variation #1



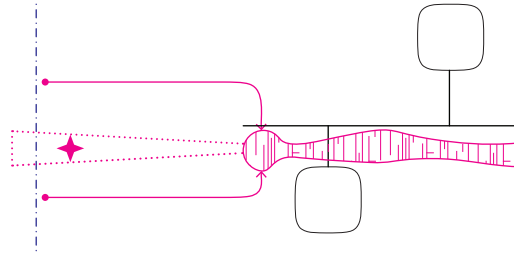
and level X inward

between the overpass and  
 penetrates through the dike on  
 placed. The path is flanked  
 s version is closer to a  
 e soil wall.



ed through AI X-Figura

variation #2



Edge: sunken X inward

A sunken passage that functions as a wadi is  
 placed between the overpass and the soil wall.  
 This effectively distances the pedestrian  
 experience from the overpass and facilitates  
 connection to the waterfront.



**Part 4**  
**Conclusion & Discussions**

4.1 Conclusion	154
4.2 Discussions	158
4.3 Reflection	166



## 4.1 Conclusion

Here all the research questions are answered in summary. Each step or component of the proposed framework is answered in the sub-questions. Together, they structure the framework and answer the main question.

### Sub-question 1

*What is the spatial extent of a waterfront in Seoul, and the area of influence regarding heat waves and flash floods in the summer?*

Width of waterfronts are found on their sunken and enclosed cross section, while their lengths are segmented based on usage - where spatial configuration forced people to choose between different possible routes.

Area of influence of waterfronts is differentiated in two scales: local and city-wide. Locally, 15-minute walking distance (1km) is buffered area outside waterfront. In city-wide scale against heatwaves, urban catchment areas (9-minute by walking, 600m) reachable within 24.28 minutes by metro were identified. City-scale area of influence under flash flood was measured on the whole automobile network inside Seoul's administrative boundary.

### Sub-question 2

*How can Seoul's waterfronts be evaluated and classified by spatial characteristics that affect daily life during extreme summers?*

Seven normalized variables calculated in RQ 2a-2d were weighed according to their impact on daily life (frequency and affected population) to group waterfronts with similar characteristics. Four groups with distinct climate adaptive performances were identified: flood-safe with high thermal relief, flood-safe with low thermal performance, vulnerable mobility if flooded, and likely to flood with low thermal performance. The results indicate waterfronts with different morphological and geographical features can be grouped together by the impact of their climate adaptive performances on daily life during extreme summer events.

### Sub-question 2a

*To what extent can waterfronts withhold floods during severe rainfalls?*

Most waterfronts showed high scores in flood buffer capacity analysis, which points to sufficient size of waterfronts to prevent overflow during severe rainfalls. However, waterfronts that displayed low scores imply their spatial characteristics were inadequate to contain runoff water inside the available space inside the waterfronts. For such cases, increase of waterfront volume or reduction of runoff water from its basin area should be considered.

### Sub-question 2b

*What is the extent of disruption on mobility networks when waterfronts become flooded?*

Flooded mobility robustness analysis presents combined effects of geographical location and the mobility networks relevant to a waterfront. Lack of correlation between local and city-wide versions exhibit the extent of segregation between pedestrian and automobile networks related to a waterfront. Upstream waterfronts, due to their higher bank levels, displayed higher disruption on the automobile traffic of the whole city, while local pedestrian networks did not follow this pattern.

### Sub-question 2c

*What is the extent of thermal relief provided by the waterfronts, compared to their surrounding urban area during heat waves?*

Analysis of thermal relief based on proxied air temperature demonstrated that the most of the sample waterfronts provided valid heat refuge to their urban surroundings. Hangang river performed consistently above average and Hongje stream with low sky view factor performed exceptionally well. While the extent in local scale was closely correlated with city-wide scale, some waterfronts displayed significantly low local scale values, which indicates the distinct spatial conditions of waterfronts surrounding area also affects the demand to visit the waterfronts during heatwaves.

### Sub-question 2d

*What is the level of accessibility to waterfronts that provide refuge from heat waves?*

Thermal refuge accessibility analysis indicates that local accessibility for most waterfronts were acceptable, in contrast to the substandard performances in city scale. This implies that location and longitudinal depth of waterfront entrances should be reconsidered for design interventions. Hangang river parks tended to perform better in both scales compared to streams.

### Sub-question 3

*Which design principles derive climate adaptive solutions that enhance quality of daily life trajectories from spatial analysis?*

Two design principles were derived to maximize the benefits of climate adaptive design interventions and increase their feasibility.

- 1) Generate multi-functional and holistic open space interventions that contribute to the quality of daily life trajectories not only in extreme climates but also in moderate climate
- 2) Prioritize public realm and minimize interventions in private plots

### Sub-question 4

*How can the proposed framework generate site-specific design interventions which stakeholders can evaluate and choose from?*

The proposed design framework consists of four steps that utilize analysis results to determine effective design locations, derive spatial strategies, generate design variations according to site conditions, and select the most optimal one based on evaluations. Topological devices that visualize possible variations of leveraging spatial elements were developed to generate site-specific options of climate adaptive designs. Processes that guide stakeholders to evaluate and select from these options were also proposed.

### Main question

*How can spatial impacts of Seoul's waterfronts on climate adaptivity be measured and leveraged to enhance trajectories of daily life?*

The climate adaptive capacities of Seoul's waterfronts that are relevant to daily life trajectories can be measured and leveraged through the proposed framework that integrates spatial analysis and design. The framework begins with waterfront definition based on usage and their area of influence under two extreme events: heatwaves and flash floods. Each defined waterfront is assessed on its performances against the two extreme events through seven spatial variables. These results, guided by a set of design principles, then identify effective design locations and spatial elements that can be leveraged with. Lastly, the framework generates various versions of how these elements can be spatialized on given sites. In summary, the framework takes a region including a waterway network as an input and produces as output 1) analysis on their current climate adaptivity related to daily life trajectories, and 2) climate adaptive design alternatives from which stakeholders can choose from.

## 4.2 Discussion

Discussions are subdivided into three parts: first the validity of the variables developed in this study is discussed, followed by discussions over the limits and scalability of the framework and its applicability in the real world. Personal reflection reviews on the whole process of conducting this study.

### 4.2.1 Validity of variables used in analysis

As discussed in 2.4.1, definition of local area discards many spatial complexities such as block configuration, existence of heavy infrastructures, or other waterfronts inside them. As the method fails to accurately outline a waterfront's actual local area, application of rcrisp's segment delineation (Forgaci & Nattino, 2025) which incorporates block configuration near waterways would refine analysis of local-scale variables.

Flood buffer capacity is a variable that is built on a number of assumptions to illustrate the interplay between the morphology of waterfronts and their surrounding environments under severe rainfalls. Therefore, it does not include factors such as drainage systems, absorption by green roofs, or lowlands where runoff water stagnates. These simplifications are likely to have led to discrepancies when compared to overflow risk projection map issued by City Hall (Figure 127), which also calculates the probability of waterways to overflow based on several rainfall scenarios.

Flooded mobility robustness is based on simulations that assume a rainfall event occurs evenly inside the city. While this is in line with how flood buffer capacity is computed, its ability to depict realistic disruptions caused by a flooding of a waterfront is limited. One amended version would be to base the simulations on past floods and restrict the impact of the waterfronts to scenarios when a district-scale rainfall causes overflows. A previous study that assessed flood risk using network centrality indices in Seoul (K. T. Kim & Song, 2016) suggest this will also effectively demonstrate disruptions on the mobility network.

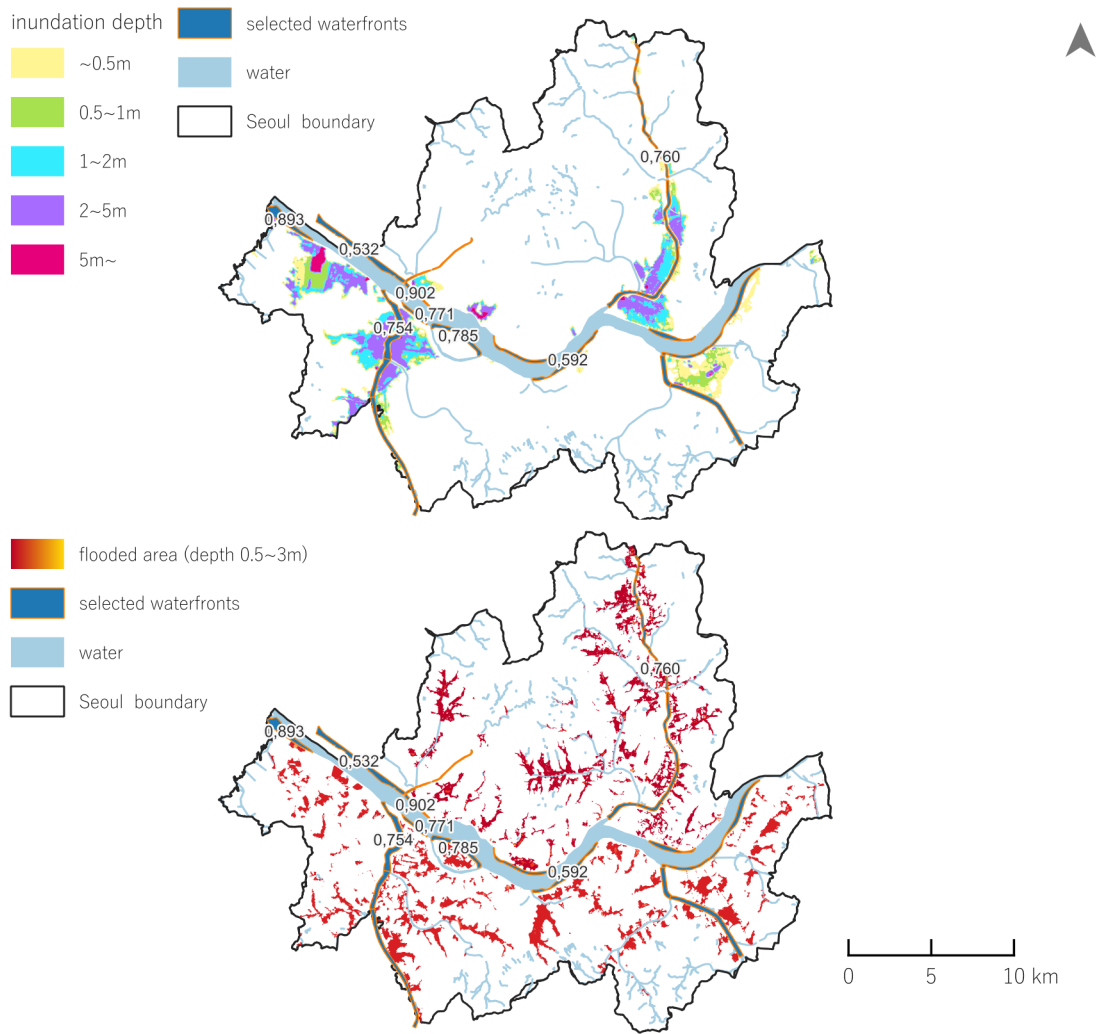


Figure 127 : Flood projection by stream overflow (top) and Inundation trace map (bottom)

While thermal relief effectively represents changes felt in air temperature, it should be noted that its correlation with thermal comfort is limited. Figure 128 shows the distribution of Discomfort Index (DI), which is a thermal comfort index that incorporates air temperature and humidity, in relation to the z-scored spatial contribution to heat. This is in line with the reality of Seoul, which is famous for high humidity during summers. However, as morphological factors impact on humidity is only implicit through wind speed, thermal relief is valid for assessing the spatial contribution to thermal comfort. Moreover, this method can be refined if more studies were conducted between the spatial contribution to thermal comfort using the wind speed data collected by S-DOT stations installed throughout Seoul.

Results on waterfront accessibility showed some discrepancies compared to a previous study (S. E. Kim et al., 2023) which reported that less than 30% of the population within 2km radius of waterfronts had access to them. This difference may be due to distinct methods of measuring accessibility; while this study focused on spatial range incorporating all entrances, Kim et al. (2023) set one representational entrance for each 1km segment and ran simulation for centroid of municipal neighborhood boundaries. The discrepancies highlight that the number of waterfront entrances contribute significantly to pedestrian accessibility.

Lastly, city-wide thermal refuge accessibility does not take into account the connectivity of the last stops. While some stops are connected to multiple buses and metro lines that provide wide coverage throughout the city, others are only part of a neighborhood bus route. This factor substantially impacts the accessibility to the waterfronts in reality; even when spatial coverages are identical, waterfronts that are connected to stops with several routes are more likely to attract non-locals during heatwaves. Therefore, this variable can be refined by combination with other indices such as degree centrality(Figure 129) or frequency of available rides.

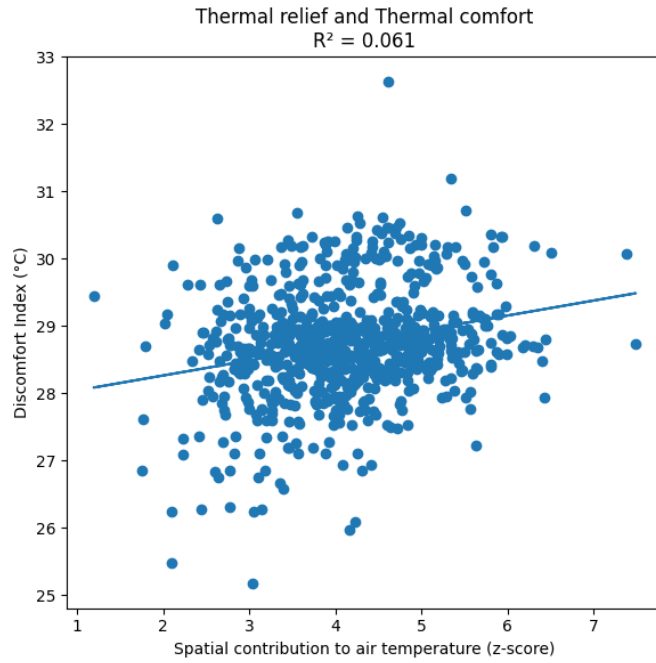


Figure 128 : Correlation between DI (Discomfort Index) and thermal relief

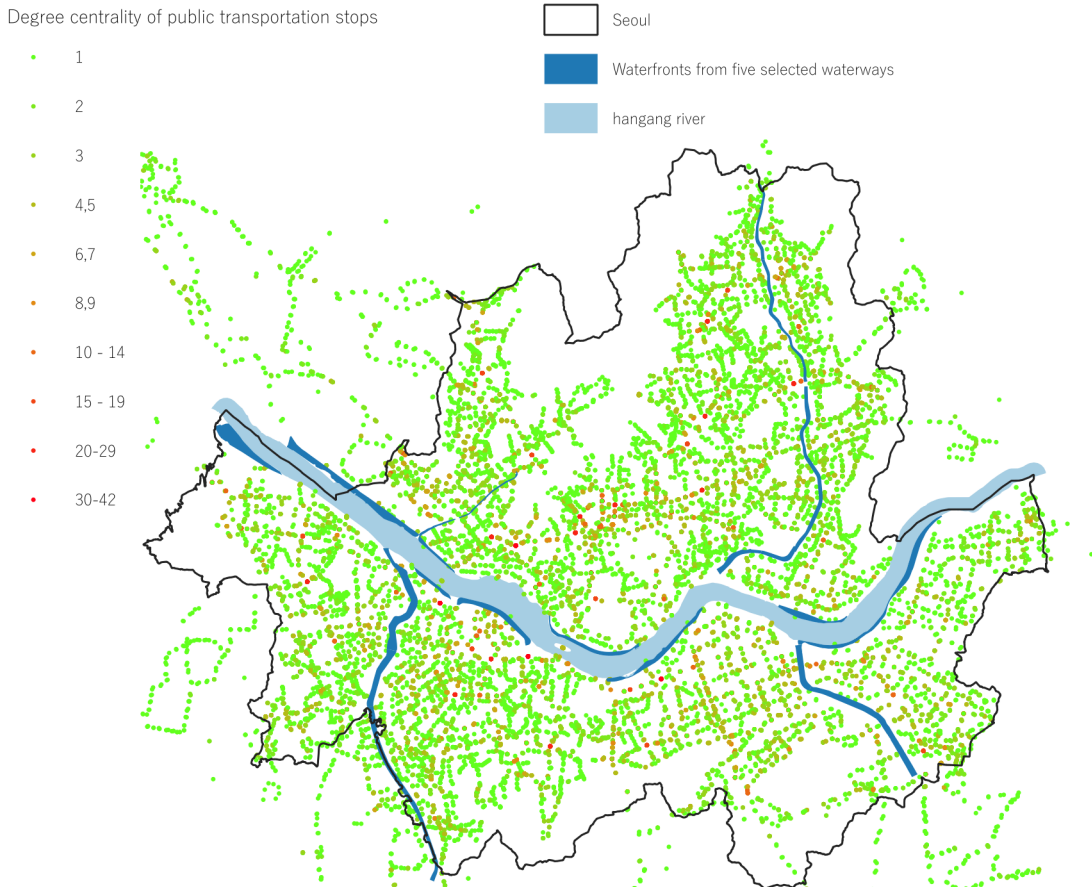


Figure 129 : Degree centrality of public transportation stops inside potential 9-min (600m) of waterfronts - bus and metro networks were merged in this calculation

#### 4.2.2 Framework - limits and potentials

The spatial applicability of the framework would have been further validated in this study if a detailed digital terrain model was able to provide more sample waterfronts. Due to lack of a high-resolution digital terrain model, waterfront definition of streams was limited to those whose boundaries were defined by adjacent roads. Owing to this constraint, some streams that were not flanked by roads were excluded. This penalty also rendered the process of identifying waterfronts into a laborious and time-consuming work that resulted in the exclusion of tributary streams. In total, the 20 selected waterfronts counted for 77.9km out of 159.1km waterways that were wider than 30m and situated in urban context inside Seoul.

Although the framework is effective for urban waterfronts, several waterfronts exist in Seoul where this framework cannot be applied. One typical example is Nodeul island, whose waterfront is a ring-shaped sunken shape with some community facilities inside the ring (Figure 129 - left). In such cases, calculation of the analysis variables would yield invalid or misleading results. Another example would be urban lakes which are enclosed by green promenades (Figure 129 - right) without any elevational change. For this type, only the heatwave related analysis would be valid.

However, provided that the challenges above are resolved and fully acknowledged, the framework can be applied to any city whose waterfronts shares the 'linear and enclosed' conditions with Seoul. This means that the framework can be easily scaled up, not only extending towards the most upstream locations, but also enables comparison between different cities, where the simulated rainfall projections and air temperature data would be attuned to each. Such up-scaling would enable the comparison of different open space configurations between different cities and open opportunities to learn from unfamiliar morphological features.

Additionally, the framework can be modified in various ways to suit the demand of the user. For example, the aspect of daily life in moderate climate can be included in the analysis, not only as an additional layer that to be considered in the design section. Specifically, landscape ecology metrics such as patch connectivity or proximity indices could be added in such analysis to demonstrate the quality of daily life trajectories around the waterfronts. Other extreme climate conditions can also be added, such as harsh wind bursts between buildings during winter. This would be possible only if additional spatial variables were devised accordingly. In summary, the framework can be modified to generate more holistic and multi-functional designs.



Figure 130 : Waterfronts on which framework cannot be applied - Nodeul island (1,2) and Seokchon Lake (3,4)

One clear limit of the design section is that it distinguishes waterfronts from its urban surroundings, thus finding itself on a dichotomy. This division, although it originates from the separated spatiality of the waterfronts in Seoul, it naturally impedes transformation of waterfronts into graduated open spaces. In other words, while it is firmly grounded on reality, it does not question whether the given configuration should be fundamentally reconsidered.

The design section can be employed for cities outside Korea, although its original conception was based on the unique Korean waterfronts. The simplicity of the topological device enables it to generate variations of spatial strategies regardless of the waterfront's sections. The urban version can be applied to many modern cities that suffer from prevalent front/back dichotomy caused by car-centered roads. Moreover, the design mechanism becomes more efficient as it is applied to various sites. The process of reducing each design iteration into abstract diagrams facilitates generation of design variations for similar site conditions. This accumulation of possible interventions can expedite creation of new designs.

As the waterfronts are sunken or enclosed by dikes, bridges of different levels can play crucial roles in pedestrian accessibility to waterfronts and connectivity of their surroundings. In terms of climate-adaptive performance, they have considerable impact on flooded mobility robustness and thermal refuge accessibility. Therefore, their roles can be reconsidered in the design section; for example, they could be included in the range of spatial elements or become a given condition in the topological device.



Figure 131 : Proposals for recent design competitions on Hangang waterfronts  
- Banpo Hangang cover park and The 2nd Sejong Center for the Performing Arts

### 4.2.3 Applicability of framework in reality

The proposed framework can be used in various ways by designers. The most passive way would be to use the analytical section to assess climate-adaptive performances of design interventions in and around waterfronts. Comparison of the status quo with projected design outcomes (Figure 131), as well as comparison of past conditions with current will present to what extent the design interventions will contribute or have contributed to the quality of daily life trajectories during extreme summers.

Some designers may object to the idea of implementing a rationalized approach of spatial design that focuses on the enhancement of certain quantifiable performances. While it can also be used for designers who wish to include climate adaptivity in their design criteria, the proposed framework evidently targets designers who desire to ensure that their design will mitigate damage from extreme climatic events worsened by climate change. Due to the quantitative variables that measure spatial performances, it is more likely to encourage public officers to experiment with possible design outcomes.

Even though the spatial elements provided by the design section of the framework were derived from the spatial variables, it is possible that designers can discover other design elements that also contribute to leveraging climate adaptive performances. In this case, they can expand the spatial strategy toolkit, keeping in mind how the new method corresponds to the topological device.

Some obvious obstacles can be expected from the final stage of the design section, especially regarding the relative weights and scoring. Although relative, some criteria will be significantly difficult to compare and score the performance or importance. The proposed steps are more of a guideline to make the process of arriving at the final design output clear and explicit, so that the reasoning behind a certain design strategy can be traced back.

Lastly, these final steps of the design section that involves stakeholders participation provides a functioning structure that can be developed into a codesign tool. The passive role given to stakeholders in the current framework can be expanded into active involvement of generating design options by use of the topological devices with designers. Their active participation in the design iterations will help them determine the relative priorities of some criteria over others, as well as discover unexpected values outside the usual and generic spectrum of evaluation criteria.

### 4.3 Reflection

This thesis was my first attempt of realizing my ambition I carried with me when I came to Bouwkunde in Delft University. Like many of my friends and colleagues who came from other continents, I began my studies here with the purpose of obtaining knowledge and skills that would contribute to the provision of better public spaces in my home country. Through all the quarters, even during the technical Geomatics courses, it was this question that never left the back of my head that powered me forward: “How is this relevant to Korean cities?” The master thesis was a great opportunity to lift this question to the surface.

What continues to amaze me, and many urbanists, is how drastically distinct are the spatial containers of life in different parts of the world, when the daily activities are fundamentally identical. Although Korean cities were developed using the same generic spatial variables such as FSI, GSI and street width-building height ratio, the resulting built environment -especially open spaces- has some unique qualities that are seldom found in their closest neighbors. In retrospect, I believe this sensation led me to devise new spatial variables tailored to Korean cities. However, the task was much more difficult than I first thought it would be. In truth, I was quite naïve to believe that what can be felt or perceived without difficulty in this world should be equally painless to be measured in numbers. Furthermore, although the project was based on the premise that spatial design can only have limited impacts under certain scenarios, I realized through quantification I had still overestimated spatial impact like a classic design-oriented urbanist.

Consequently, I ended up deriving variables based on simplified models of reality that exclude many factors; not only non-spatial but also spatial factors whose data could not be obtained. My confidence in the project decreased as the models became cruder to highlight spatial impacts. However, the more I read, the more I was comforted to discover other studies were also conducted under clear limitations. I realized what matters the most is that you are fully aware of the limitations and what they signify in the real world. Once I accepted this, I was able to enjoy the process instead of being tormented by its faults.

Data driven design was one of the skillsets I wanted to bring back home from Delft. However, my attempts in the previous quarters that did not satisfy my standards continued to frustrate me and led me to believe I had to be more invested in the production of data. Eventually I realized that the design section had to be addressed with equal weight as I began yielding results. Although production of analysis results that could be used by designers is a valid objective, it was even more meaningful to demonstrate how such data could be used to generate design. I am glad I took this task seriously, as I took great pleasure in discovering ways to let non-generic data guide design.

I believe this thesis is only the first step of many that will be powered by that question that will always have a special place reserved in my head. It has given me the courage to ‘swing the bat’ despite the fear of striking out, because it’s the only thing that will get me closer to hitting the actual ball.

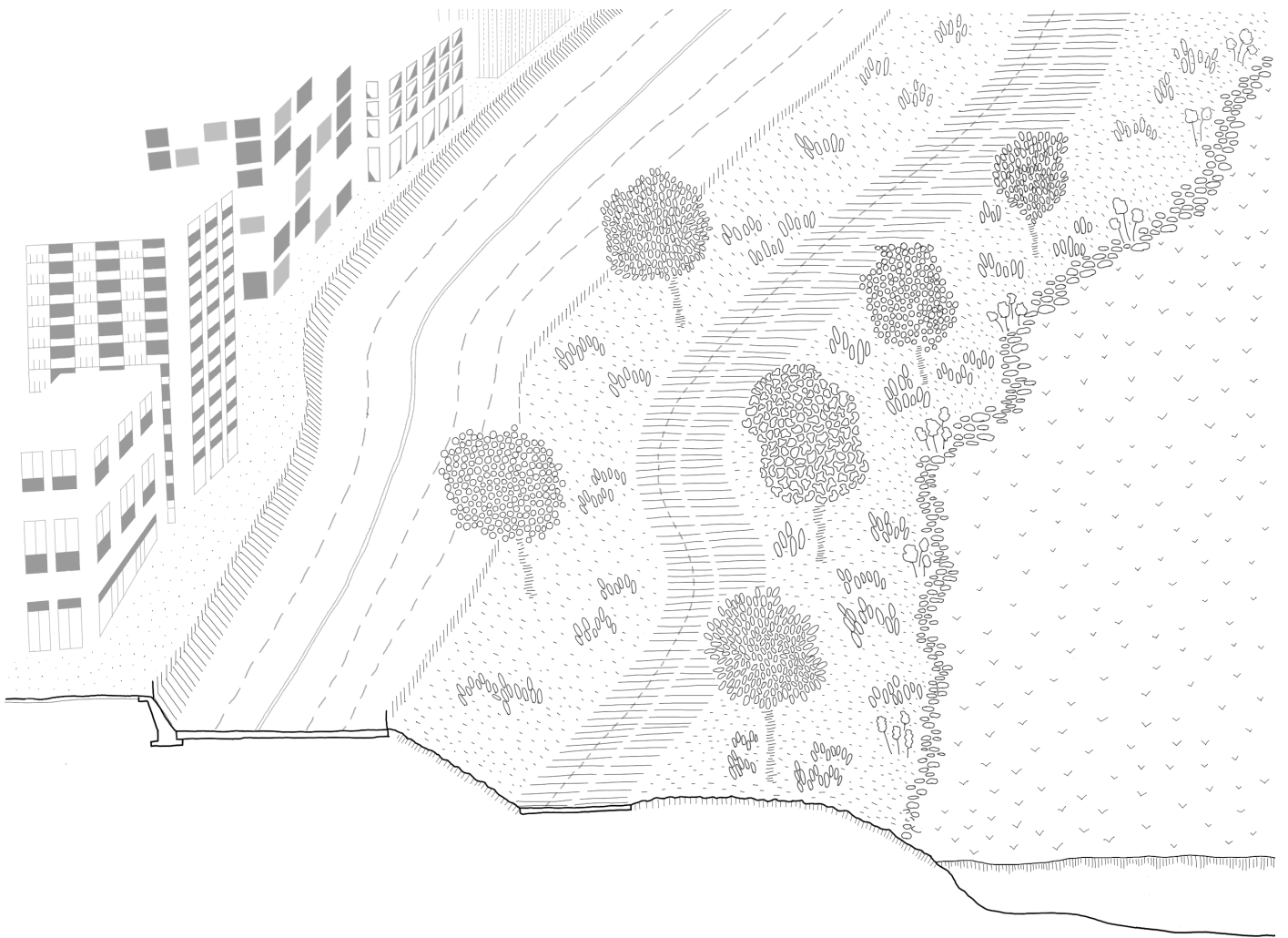


Figure 132 : Typical layout of urban waterfronts in Seoul

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## List of Figures

#	name	source
1	Restored Ceonggyecheon: quintessential waterfront of Seoul	The Seoul Institute (2014) <a href="https://data.si.re.kr/node/50004">https://data.si.re.kr/node/50004</a>
2	Different morphologies of Seoul's waterfronts and affected daily life during extreme summers	The Seoul Institute 1: <a href="https://data.si.re.kr/node/61936">https://data.si.re.kr/node/61936</a> (2020) 2: <a href="https://data.si.re.kr/node/64980">https://data.si.re.kr/node/64980</a> (2020) 3: <a href="https://data.si.re.kr/node/60560">https://data.si.re.kr/node/60560</a> (2020) 4: <a href="https://data.si.re.kr/node/61962">https://data.si.re.kr/node/61962</a> (2020) 5: Chosun Media (2025), <a href="https://www.chosun.com/national/national_general/2025/08/14/IUG6OSMQC5HB3FICZUZSYG2XTM/">https://www.chosun.com/national/national_general/2025/08/14/IUG6OSMQC5HB3FICZUZSYG2XTM/</a> 6: Kukminilbo (2018), <a href="https://www.kmib.co.kr/article/view.asp?arcid=0923961314">https://www.kmib.co.kr/article/view.asp?arcid=0923961314</a>
3	Structure of proposed framework	
4	Land surface temperature distribution of Seoul	Li, Y., Lee, S., & Han, J. (2019). Analysis of the Relationship between Three-Dimensional Built Environment and Urban Surface Temperature. <i>Journal of Korea Planning Association</i> , 54(2), 93-108. <a href="https://doi.org/10.17208/jkpa.2019.04.54.2.93">https://doi.org/10.17208/jkpa.2019.04.54.2.93</a>
5	Flood risk projection (~0.5m at 100mm/hr) of Seoul	Seoul Open Data Plaza (2023), <a href="https://data.seoul.go.kr/dataList/OA-21172/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21172/S/1/datasetView.do</a>
6	Bulgwang stream cherry blossom festival	Eunpyeong-gu Council (2022), <a href="https://council.ep.go.kr/kr/chairman/photoBBSview.do?uid=E65770EA91EBFCBF1C24A5DD43F28195">https://council.ep.go.kr/kr/chairman/photoBBSview.do?uid=E65770EA91EBFCBF1C24A5DD43F28195</a>
7	1975-2025 Trend of heavy rain fall frequency in South Korea	Presidential Water Commission (2020), <a href="https://www.water.go.kr/469">https://www.water.go.kr/469</a>
8	1975-2025 Trend of heatwaves in Seoul	
9	1975-2025 Monthly rainfall in Seoul	KMA Weather Data Service (2026), <a href="https://data.kma.go.kr/climate/RankState/selectRankStatisticsDivisionList.do">https://data.kma.go.kr/climate/RankState/selectRankStatisticsDivisionList.do</a>
10	1975-2025 Monthly highest temperature in Seoul	
11	Five selected waterway with district boundaries	Water - OSM Districts - Seoul Data Hub (2024), <a href="https://data.seoul.go.kr/bsp/wgs/dataView/data300View/10080.do">https://data.seoul.go.kr/bsp/wgs/dataView/data300View/10080.do</a>
12	Conceptual framework	
13	Structure of theoretical framework-Environmental urban morphology's application to Seoul's waterfronts	
14	Application of spatial framework on research questions	
15	Process of waterfront definition	
16	Spaces excluded in waterfront definition in this study	Naver Map Satellite and street view
17	Locally influenced area of 15min potential aea and city-wide influenced area during heatwaves	
18	Structure of evaluation and classification of waterfronts in this study	
19	IDF(Intensity-Duration-Frequency) curve conversion to 24hour hyetograph	Elfeki, A. M. (2025). AI-Generated Code to Transfer IDF Curve to Hyetograph by Alternating Block Method. <a href="https://doi.org/10.13140/RG.2.2.10905.12648">https://doi.org/10.13140/RG.2.2.10905.12648</a> , Yoon, S.-K., & Choi, H. (2019). 서울시 기후변화 영향을 고려한 확률강우량 산정 [Estimation of the future probable precipitation in accordance with the changing climate in Seoul]. Seoul Institute of Technology.
20	Catchment basins included in this study	SRTM 1 Arc-Second Global (Digital Object Identifier (DOI) number: /10.5066/F7PR7TFT)
21	Discharge flow rate of Anyang's waterfronts during simulated rainfall	
22	Flood buffer capacity calculation process	
23	Simulated mobility networks and areas of influence for local and city-wide scale	Seoul Open Data Plaza (2024), <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> , OSM - Roads
24	Flooded mobility robustness calculation process	
25	Thermal relief caculation process	
26	Computed isochrones for thermal refuge accessibility in Hangang 1s	Seoul Open Data Plaza (2024), <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a>

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27	Thermal refuge accessibility calculation process	
28	Process of deriving design principles	
29	Process of producing site-specific design variations	
30	Names and locations of 20 segmented waterfronts	OSM - Water, Roads
31	Three locations where waterfront could not be defined	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
32	Typical section and spatial configuration of five waterways	The Seoul Institute Hongje: <a href="https://data.si.re.kr/node/60560">https://data.si.re.kr/node/60560</a> (2020) Jungrang: <a href="https://data.si.re.kr/node/64980">https://data.si.re.kr/node/64980</a> (2020) Anyang: <a href="https://data.si.re.kr/node/45995">https://data.si.re.kr/node/45995</a> (2015) Tan: <a href="https://data.si.re.kr/node/61962">https://data.si.re.kr/node/61962</a> (2020) Hangang river: <a href="https://data.si.re.kr/node/60693">https://data.si.re.kr/node/60693</a> (2020)
33	Locally influenced areas of 20 defined waterfronts	
34	City-wide influenced areas of waterfront Anyang-1 during heatwaves	OSM - Water, Roads
35	Correlation between local and city-wide thermal relief	
36	Correlation between local and city-wide thermal refuge accessibility	
37	Correlation between local and city-wide flooded mobility robustness	
38	Range of climate adaptive performances shown in butterfly radar chart	
39	Overlapped climate adaptive performances of five selected waterways	
40	Range of weighted climate adaptive performances shown in butterfly radar chart	
41	Five waterfront types as result of qualitative classification of weighted variables	
42	Geographical distribution of five waterfront types	OSM - Water, Roads
43	Scatterplot of waterfronts by comprehensive performances against heatwaves and flash floods	
44	Diagram of first design principle - Adaptive Everyday Network	
45	Diagram of second design principle - Public Stitchwork	
46	Design process diagram	
47	Identification of effective intervention locations	
48	Climate adaptive performances in need of improvement by waterfront type	
49	Spatial elements relevant to each climate adaptive performance	
50	Two topological devices for spatialization and interconnection	
51	Evaluation and selection process diagram	
52	Location of three selected waterfronts for design implementations	OSM - Water
53	Distribution of three selected waterfronts in climate adaptivity scatterplot	
54	Typical spatial configuratoin of three waterfronts	The Seoul Institute Jungrang-3 : <a href="https://data.si.re.kr/node/58671">https://data.si.re.kr/node/58671</a> (2020) Hongje-3: <a href="https://data.si.re.kr/node/42103">https://data.si.re.kr/node/42103</a> (2008) Hangang-1S: <a href="https://data.si.re.kr/node/61935">https://data.si.re.kr/node/61935</a> (2020)
55	Location of waterfront Jungrang-3	OSM - Water
56	Waterfront and local area boundaries of Jungrang-3	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
57	Birdseyeview of waterfront Jungrang-3 and its local area	

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58	Relationships with adjacent infrastructures in Jungrang stream	The Seoul Institute 1: <a href="https://data.si.re.kr/node/61243">https://data.si.re.kr/node/61243</a> (2020) 2: <a href="https://data.si.re.kr/node/58898">https://data.si.re.kr/node/58898</a> (2020) 3: <a href="https://data.si.re.kr/node/65018">https://data.si.re.kr/node/65018</a> (2020) 4: <a href="https://blog.naver.com/alice8565/222345365929">https://blog.naver.com/alice8565/222345365929</a> (2021)
59	Analysis of Jungrang-3's climate adaptive performances against heatwaves	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> OSM -Buildings, Water
60	Analysis of Jungrang-3's climate adaptive performances against flash floods	OSM -Roads, Landuse Land Surface Type Map (2026), <a href="https://aid.mcee.go.kr/intro/land.do">https://aid.mcee.go.kr/intro/land.do</a>
61	Analysis of Jungrang-3's pedestrian connectivity during moderate climate	OSM - Landuse, Points of interest, Road
62	Jungrang-3's conclusion map overlapping performances under three climatic scenarios	
63	Butterfly chart of Jungrang-3's comprehensive climate adaptivity	
64	Spatial elements that can be leveraged for Jungrang-3	
65	Typical cross-section of Jungrang stream	
66	Range of spatial elements applicable in typical site conditions of Jungrang-3	The Seoul Institute 1: <a href="https://data.si.re.kr/node/58898">https://data.si.re.kr/node/58898</a> (2020) 2: <a href="https://blog.naver.com/alice8565/222345365929">https://blog.naver.com/alice8565/222345365929</a> (2021) 3: Naver Map Streetview (2026), 4: <a href="https://m.blog.naver.com/eulsoo95/221450890725">https://m.blog.naver.com/eulsoo95/221450890725</a> (2019)
67	Plan of Jungrang-3 North	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
68	Points of interests and site conditions of Jungrang-3 North	1: 내손안의서울 [Seoul Media Hub] (2021), <a href="https://mediahub.seoul.go.kr/archives/2001519">https://mediahub.seoul.go.kr/archives/2001519</a> 2: <a href="https://m.blog.naver.com/eulsoo95/221450890725">https://m.blog.naver.com/eulsoo95/221450890725</a> (2019) 3-4: Naver map aerial view and streetview (2026)
69	Spatial elements applied in sites of Jungrang-3 North	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
70	Application of topological device to produce first design iteration in Jungrang-3 North's sites	
71	First design iteration in Jungrang-3 North's sites: plan, extracted diagram and section perspectives	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
72	First design iteration in Jungrang-3 North's site A varied into two other versions using abstract diagram and visualized through AI X-Figura	
73	First design iteration in Jungrang-3 North's site B varied into two other versions using abstract diagram and visualized through AI X-Figura	
74	First design iteration in Jungrang-3 North's site C varied into two other versions using abstract diagram and visualized through AI X-Figura	

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75	Plan of Jungrang-3 South	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
76	Points of interests and site conditions of Jungrang-3 South	1: <a href="https://blog.naver.com/soo_soobak/222244308631?viewType=pc">https://blog.naver.com/soo_soobak/222244308631?viewType=pc</a> (2021) 2: 내손안의서울 [Seoul Media Hub] (2020), <a href="https://mediahub.seoul.go.kr/archives/1503119">https://mediahub.seoul.go.kr/archives/1503119</a> 3-4: Naver Map Streetview (2026)
77	Spatial elements applied in sites of Jungrang-3 South	The Seoul Institute 1: <a href="https://data.si.re.kr/node/60559">https://data.si.re.kr/node/60559</a> (2020) 2: <a href="https://data.si.re.kr/node/47188">https://data.si.re.kr/node/47188</a> (2014) 3-4: Naver Map Streetview (2026)
78	Application of topological device to produce first design iteration in Jungrang-3 South's sites	
79	First design iteration in Jungrang-3 South's sites: plan, extracted diagram and section perspectives	
80	First design iteration in Jungrang-3 South's site A varied into two other versions using abstract diagram and visualized through AI X-Figura	
81	First design iteration in Jungrang-3 South's site B varied into two other versions using abstract diagram and visualized through AI X-Figura	
82	Location of waterfront Hongje-3	
83	Waterfront and local area boundaries of Hongje-3	
84	Birdseyeview of waterfront Hongje-3 and its local area	
85	Relationships with adjacent infrastructures in Hongje stream	
86	Analysis of Hongje-3's climate adaptive performances against heatwaves	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> OSM -Buildings, Water
87	Analysis of Hongje-3's climate adaptive performances against flash floods	OSM -Roads, Landuse Land Surface Type Map (2026), <a href="https://aid.mcee.go.kr/intro/land.do">https://aid.mcee.go.kr/intro/land.do</a>
88	Analysis of Hongje-3's pedestrian connectivity during moderate climate	OSM - Landuse, Points of interest, Road
89	Hongje-3's conclusion map overlapping performances under three climatic scenarios	
90	Butterfly chart of Hongje-3's comprehensive climate adaptivity	
91	Spatial elements that can be leveraged for Hongje-3	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
92	Typical cross-section of Hongje stream	
93	Range of spatial elements applicable in typical site conditions of Hongje-3	1, 2, 4: Naver Map Streetview 3: <a href="https://www.hani.co.kr/arti/area/capital/1125764.html">https://www.hani.co.kr/arti/area/capital/1125764.html</a> (2024)
94	Plan of Hongje-3	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water

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95	Points of interests and site conditions of Hongje-3	1: <a href="https://www.hani.co.kr/arti/area/capital/1125764.html">https://www.hani.co.kr/arti/area/capital/1125764.html</a> (2024) 2, 3: Naver Map Streetview 4: 내손안의서울[Seoul Media Hub] (2022), <a href="https://mediahub.seoul.go.kr/archives/2004600">https://mediahub.seoul.go.kr/archives/2004600</a>
96	Spatial elements applied in sites of Hongje-3	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
97	Application of topological device to produce first design iteration in Hongje-3's sites	
98	First design iteration in Hongje-3's sites: plan, extracted diagram and section perspectives	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
99	First design iteration in Hongje-3's site A varied into two other versions using abstract diagram and visualized through AI X-Figura	
100	First design iteration in Hongje-3's site B varied into two other versions using abstract diagram and visualized through AI X-Figura	
101	Location of waterfront Hangang-1S	
102	Waterfront and local area boundaries of Hangang-1S	
103	Birdseyeview of waterfront Hangang-1S and its local area	
104	Relationships with adjacent infrastructures in Hangang river	The Seoul Institute (2020) 1: <a href="https://data.si.re.kr/node/61936">https://data.si.re.kr/node/61936</a> 2: <a href="https://data.si.re.kr/node/61935">https://data.si.re.kr/node/61935</a> 3: <a href="https://data.si.re.kr/node/61949">https://data.si.re.kr/node/61949</a> 4: <a href="https://data.si.re.kr/node/56390">https://data.si.re.kr/node/56390</a>
105	Analysis of Hangang-1S's climate adaptive performances against heatwaves	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> OSM -Buildings, Water
106	Analysis of Hangang-1S's climate adaptive performances against flash floods	OSM -Roads, Landuse Land Surface Type Map (2026), <a href="https://aid.mcee.go.kr/intro/land.do">https://aid.mcee.go.kr/intro/land.do</a>
107	Analysis of Hangang-1S's pedestrian connectivity during moderate climate	OSM - Landuse, Points of interest, Road
108	Hangang-1S's conclusion map overlapping performances under three climatic scenarios	
109	Butterfly chart of Hangang-1S's comprehensive climate adaptivity	
110	Spatial elements that can be leveraged for Hangang-1S	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
111	Typical cross-section of Hangang river	
112	Range of spatial elements applicable in typical site conditions of Hangang-1S	1: 내손안의 서울 [Seoul Media Hub] (2017), <a href="https://mediahub.seoul.go.kr/archives/1130003">https://mediahub.seoul.go.kr/archives/1130003</a> 2,3: Naver Map Streetview (2026) 4: The Seoul Institute (2020), <a href="https://data.si.re.kr/node/61853">https://data.si.re.kr/node/61853</a>
113	Plan of Hangang-1S North	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water

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114	Points of interests and site conditions of Hangang-1S West	1: 내손안의 서울 [Seoul Media Hub] (2017), <a href="https://mediahub.seoul.go.kr/archives/1130003">https://mediahub.seoul.go.kr/archives/1130003</a> 2: <a href="https://www.newstree.kr/newsView/ntr202411270013">https://www.newstree.kr/newsView/ntr202411270013</a> (2024) 3: The Seoul Institute (2020), <a href="https://data.si.re.kr/node/61853">https://data.si.re.kr/node/61853</a> 4: <a href="https://www.chosun.com/national/national_general/2024/04/04/O4WBSOOLGVBPDAK4FSUYA6KM4/">https://www.chosun.com/national/national_general/2024/04/04/O4WBSOOLGVBPDAK4FSUYA6KM4/</a> (2024)
115	Spatial elements applied in sites of Hangang-1S West	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
116	Application of topological device to produce first design iteration in Hangang-1S West's sites	
117	First design iteration in Hangang-1S West's sites: plan, extracted diagram and section perspectives	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
118	First design iteration in Hangang-1S West's site A varied into two other versions using abstract diagram and visualized through AI X-Figura	
119	First design iteration in Hangang-1S West's site B varied into two other versions using abstract diagram and visualized through AI X-Figura	
120	Plan of Hangang-1S East	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
121	Points of interests and site conditions of Hangang-1S East	1: <a href="https://www.dnews.co.kr/uhtml/view.jsp?idxn=202106071222360340321">https://www.dnews.co.kr/uhtml/view.jsp?idxn=202106071222360340321</a> (2021) 2-3: 내손안의서울 [Seoul Media Hub] (2015), <a href="https://mediahub.seoul.go.kr/archives/839434">https://mediahub.seoul.go.kr/archives/839434</a> 4: Naver Map Streetview (2026)
122	Spatial elements applied in sites of Hangang-1S East	ESRI Satellite image (2026), <a href="https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9">https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9</a>
123	Application of topological device to produce first design iteration in Hangang-1S East's sites	
124	First design iteration in Hangang-1S East's sites: plan, extracted diagram and section perspectives	Seoul Open Data Plaza -Trees (2026): <a href="https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22904/S/1/datasetView.do</a> -Pedestrian network (2024): <a href="https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21208/S/1/datasetView.do</a> -Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a> OSM -Buildings, Water
125	First design iteration in Hangang-1S East's site A varied into two other versions using abstract diagram and visualized through AI X-Figura	
126	First design iteration in Hangang-1S East's site B varied into two other versions using abstract diagram and visualized through AI X-Figura	
127	Flood projection by stream overflow (top) and Inundation trace map (bottom)	Seoul Open Data Plaza Flood projection (2023): <a href="https://data.seoul.go.kr/dataList/OA-21172/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-21172/S/1/datasetView.do</a> Inundation trace (2025): <a href="https://data.seoul.go.kr/dataList/OA-15636/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-15636/F/1/datasetView.do</a>

#	name	source
128	Correlation between DI (Discomfort Index) and thermal relief	Seoul Open Data Plaza (2026), <a href="https://data.seoul.go.kr/dataList/OA-15969/S/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-15969/S/1/datasetView.do</a>
129	Degree centrality of public transportation stops inside potential 9-min (600m) of waterfronts – bus and metro networks were merged in this calculation	Seoul Open Data Plaza –Bus stops (2025): <a href="https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do">https://data.seoul.go.kr/dataList/OA-22187/F/1/datasetView.do</a>
130	Waterfronts on which framework cannot be applied – Nodeul island (1,2) and Seokchon lake (3,4)	The Seoul Institute 1: <a href="https://data.si.re.kr/node/46787">https://data.si.re.kr/node/46787</a> (2015) 2: <a href="https://data.si.re.kr/node/43456">https://data.si.re.kr/node/43456</a> (2010) 3: <a href="https://data.si.re.kr/node/62000">https://data.si.re.kr/node/62000</a> (2020) 4: <a href="https://data.si.re.kr/node/47987">https://data.si.re.kr/node/47987</a> (2014)
131	Proposals for recent design competitions on Hangang waterfronts– Banpo Hangang cover park and The 2nd Sejong Center for the Performing Arts	내손안의서울 [Seoul Media Hub] –Banpo Hangang cover park (2024), <a href="https://mediahub.seoul.go.kr/archives/2011406">https://mediahub.seoul.go.kr/archives/2011406</a> –The 2nd Sejong Center for the Performing Arts (2023): <a href="https://mediahub.seoul.go.kr/archives/2007344">https://mediahub.seoul.go.kr/archives/2007344</a>
132	Typical layout of urban waterfronts in Seoul	

## List of Tables

#	name
1	Summary of methods used in the study, in relation to research sub-questions
2	Size of 20 defined waterfronts
3	Spatial variables related to climate adaptivity against heatwaves
4	Spatial variables related to climate adaptivity against flash floods
5	Relative weighing system of seven climate adaptivity variables
6	Example evaluation of design alternatives in Jungrang-3 North site A
7	Example relative weights of evaluation criteria used for Jungrang-3 North site A

## Appendices

A : Coefficients used to calculate variables	182
B : Classification based on original variables	184
C : Climate adaptivity analysis of 30 waterfronts	186
D : Process of deriving design elements from variables	188
E : Design iterations	190
F : Design case studies	196



## Appendix A : Coefficients used to calculate variables

### Flood buffer capacity

Land Use	Runoff Coefficient
Commercial	0.7
Residential	0.6
Transportation	0.8
Agriculture	0.3
Open soil	0.45
Grass	0.2
Forest	0.15
Wetland	0.5
Public	0.4
Industrial	0.7

Coefficients from the table below (translated by author) based on Mulvaney's methods were adapted to suit land use categorization provided by the dataset.

Table 5 Runoff coefficients in urban and agricultural regions

토지이용		C	토지이용		C		
Commercial	Center	0.70-0.95	Streets/Sidewalks		0.75-0.85		
	Neighborhood	0.50-0.70	Roofs		0.75-0.95		
Residential	Single house	0.30-0.50	Grass	Sandy	Flat (2%)	0.05-0.10	
	Collective single houses	0.40-0.60			Sloped (2-7%)	0.10-0.15	
	Townhouses	0.60-0.75			Sharply Sloped (7%~)	0.15-0.20	
	Suburban	0.25-0.40		Clay	Flat (2%)	0.13-0.17	
	Apartments	0.50-0.70			Sloped (2-7%)	0.18-0.22	
Industrial	Sparse	0.50-0.80	Agriculture	Empty	Sharply Sloped (7%~)	0.25-0.35	
	Dense	0.60-0.90			Flat	0.30-0.60	
Parks and graveyards		0.10-0.25		Rough	0.20-0.50		
Sports field		0.20-0.35		Cultivated	Sandy	With crops	0.30-0.60
Railways		0.20-0.40				No crops	0.20-0.50
Undeveloped		0.10-0.30			Clay	With crops	0.20-0.40
						No crops	0.10-0.25
Roads	Asphalt	0.70-0.95		Open field	Sandy	0.15-0.45	
	Concrete	0.80-0.95			Clay	0.05-0.25	
	Brick	0.70-0.85			Forest	0.05-0.25	

Kwon, Tae-Geun (2020). Measures for Improving Urban Park Water balance by Estimating Run Off Coefficients by Land Cover Types [토지피복 유형별 유출계수 산정을 통한 도시공원의 물수지 개선방안]. <http://www.riss.kr/link?id=T15534011>

Thermal relief

**Table 6.** Spatial regression results when the dependent variable is mean daytime temperature.

Variable	OLS	SLM	SEM	RSLM
<b>Land use variables</b>				
Low-density residential (50 m)	0.208	0.242	0.229	0.239
Medium-density residential (50 m)	0.496 ***	0.518 ***	0.506 ***	0.517 ***
High-density residential (200 m)	0.469 ***	0.526 ***	0.570 ***	0.522 ***
Low-density commercial (200 m)	-0.417 **	-0.31 *	-0.357 *	-0.318 *
Medium- and high-density commercial (50 m)	0.444	0.466	0.453	0.464
Industrial (50 m)	0.383 ***	0.401 **	0.376 *	0.399 **
Greenery (500 m)	0.196	0.271	0.075	0.266
Road (500 m)	2.381 ***	1.927 ***	2.038 ***	1.961 ***
<b>Urban form variables</b>				
Sky view factor	0.516 *	0.524 *	0.552 **	0.524 *
Porosity	0.794	0.702	0.606	0.709
Mean aspect ratio (100 m)	0.063	0.056	0.068	0.056
Built-up area ratio (50 m)	2.066 ***	1.961 ***	1.977 ***	1.969 ***
Floor area ratio (500 m)	0.052 *	0.047 *	0.040	0.048 *
Mean building height (400 m)	-0.022 **	-0.016 *	-0.019 **	-0.016 *
Roughness (50 m)	-0.007	-0.009 *	-0.009 **	-0.009 *
<b>Spatial coefficients</b>				
Spatial lag ( $\rho$ )		0.263 ***		0.244 ***
Spatial error ( $\lambda$ )			0.292 ***	
<b>Model metrics</b>				
Lagrange Multiplier (lag)		40.436 ***		
Robust Lagrange Multiplier (lag)		1.891		
Lagrange Multiplier (error)			39.739 ***	
Robust Lagrange Multiplier (error)			1.194	
R <sup>2</sup>	0.223	0.258	0.261	0.223
Log likelihood	-1353.18	-1335.35	-1334.87	
Akaike information criterion	2738.37	2704.69	2701.74	
Schwarz criterion	2817.87	2789.16	2781.25	
Breusch-Pagan	534.275 ***	451.501 ***	477.104 ***	

\*  $p < 0.1$ , \*\*  $p < 0.05$ , and \*\*\*  $p < 0.01$ .

**Table A1.** Basic floor area ratio limits of each land use category.

Land Use Type	Basic Floor Area Ratio Limit
Low-density residential	1.5
Medium-density residential	2.0
High-density residential	4.0
Low-density commercial	6.0
Medium- and high-density commercial	10.0
Industrial	4.0
Greenery	N.A.
Road	N.A.

Source: Urban Planning Ordinances of Seoul (<https://legal.seoul.go.kr/>, accessed 5 January 2025).

Kim, M., Won, J., & Kim, H. (2025). Assessing Land Use and Urban Form Effects on Summer Air Temperatures Using a City-Wide Environmental Sensor Network in Seoul, South Korea. *Land*, 14(8), 1628. <https://doi.org/10.3390/land14081628>

## Appendix B : Climate adaptivity analysis of 30 waterfronts



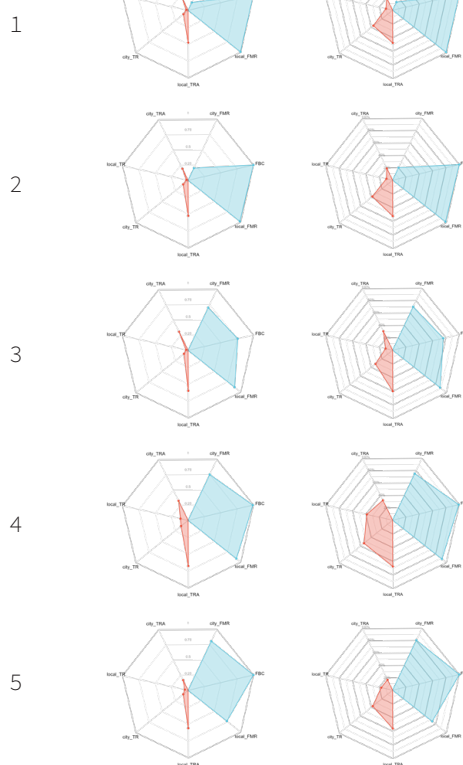
Hangang river





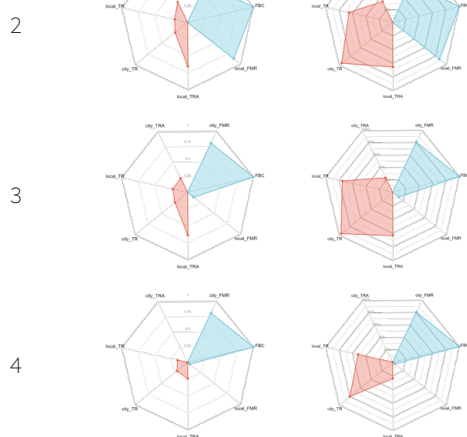
Jungrang stream

original      weighted



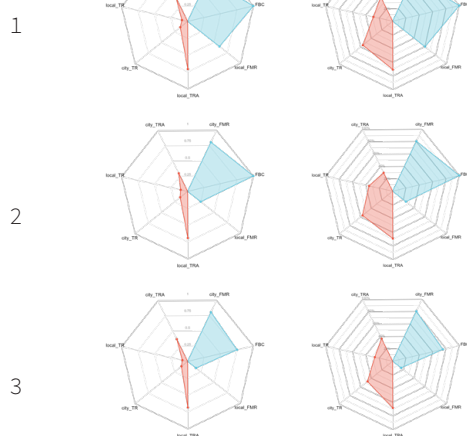
Hongje stream

original      weighted



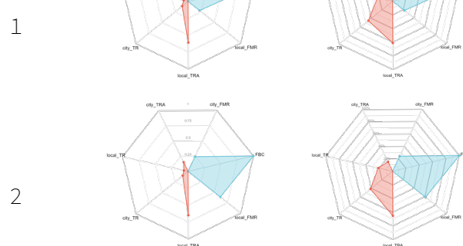
Anyang stream

original      weighted



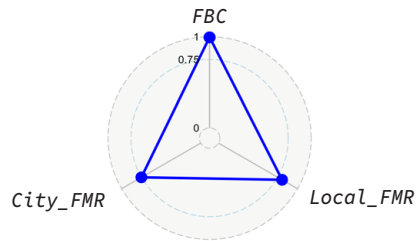
Tan stream

original      weighted

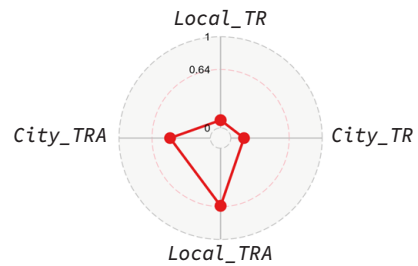


## Appendix C : Classification based on original variables

Example: Hangang-3N

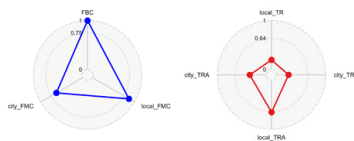


Flash floods

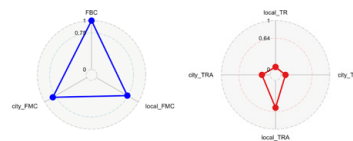


Heatwaves

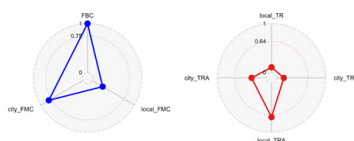
**Type # 1**  
Flood-safe  
& High thermal performance



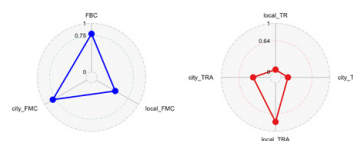
**Type # 2**  
Flood-safe  
& Low thermal performance



**Type # 3**  
Vulnerable mobility if flooded  
& Low/Moderate thermal performance

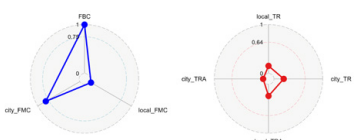


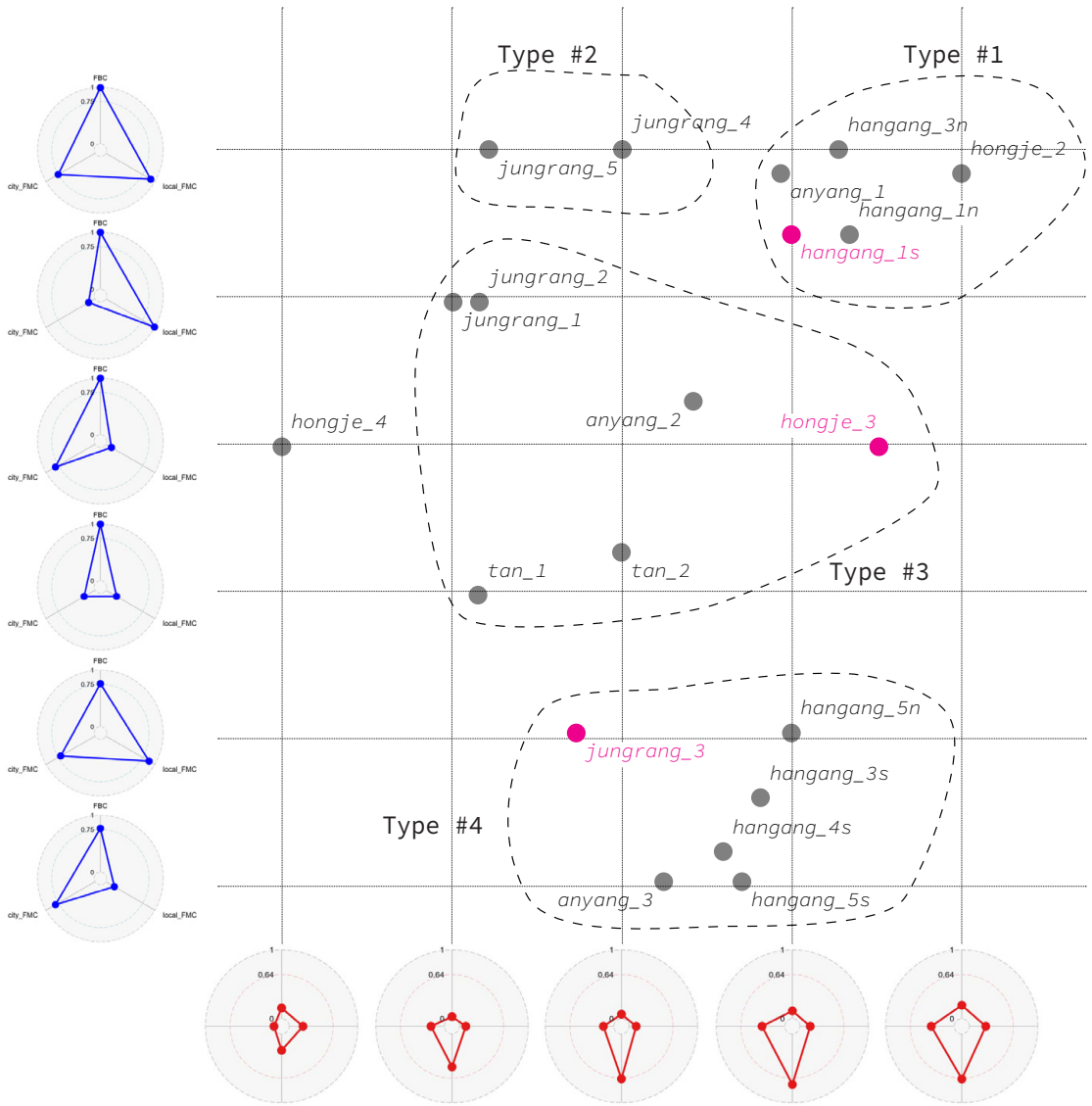
**Type # 4**  
Likely to overflow  
& Moderate/High thermal performance



### Exception

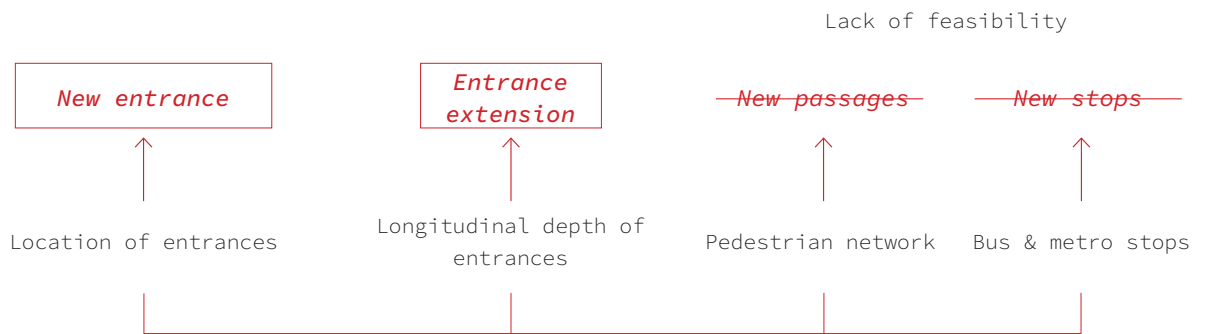
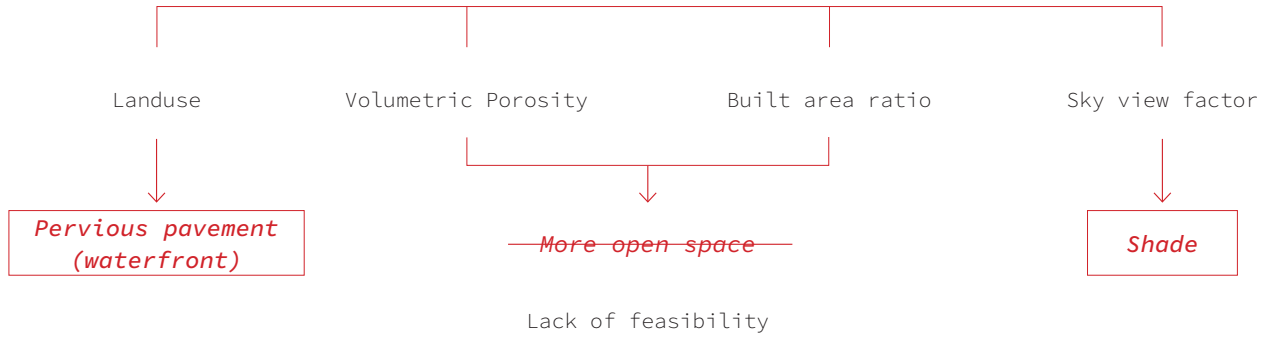
Local mobility vulnerable if flooded  
& Inaccessible heat refuge







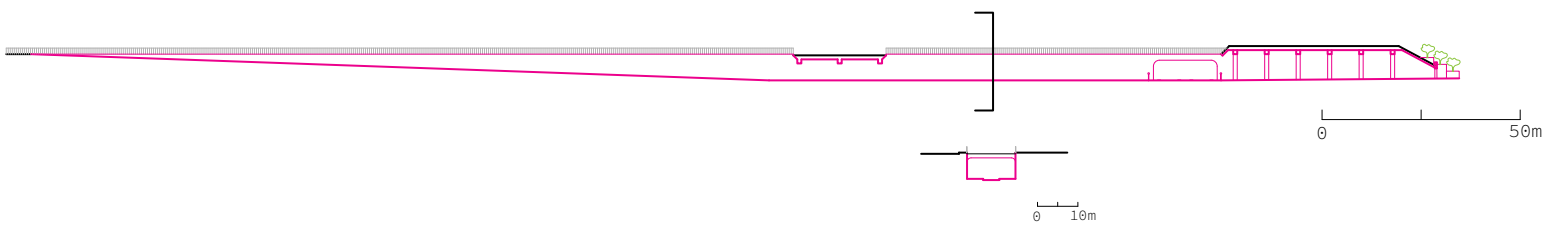
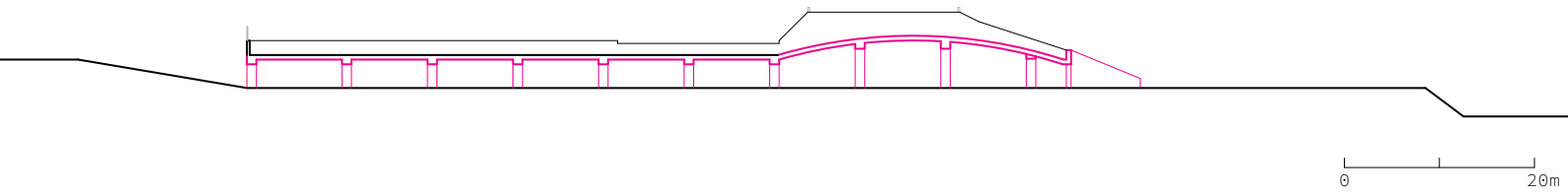
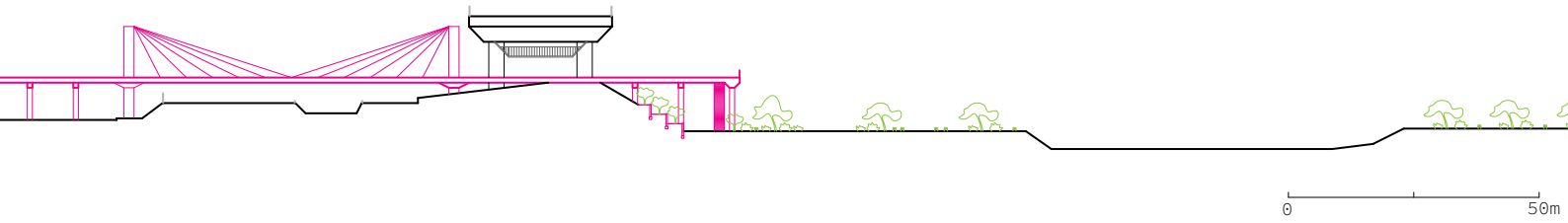
## Thermal Relief



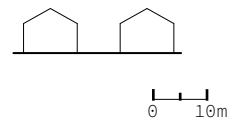
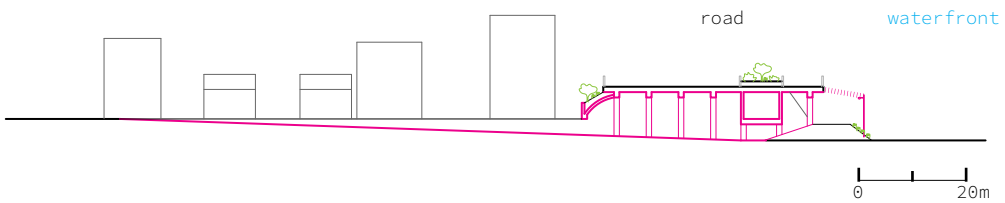
## Thermal Refuge Accessibility

# Appendix E : Design iterations

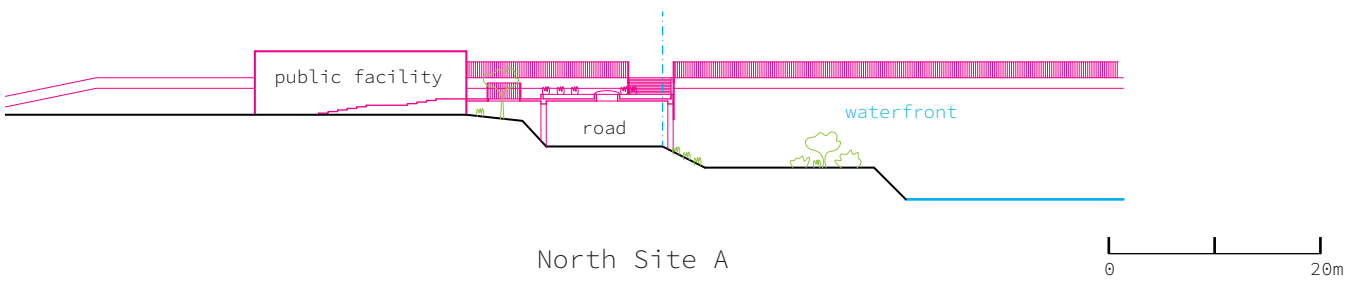
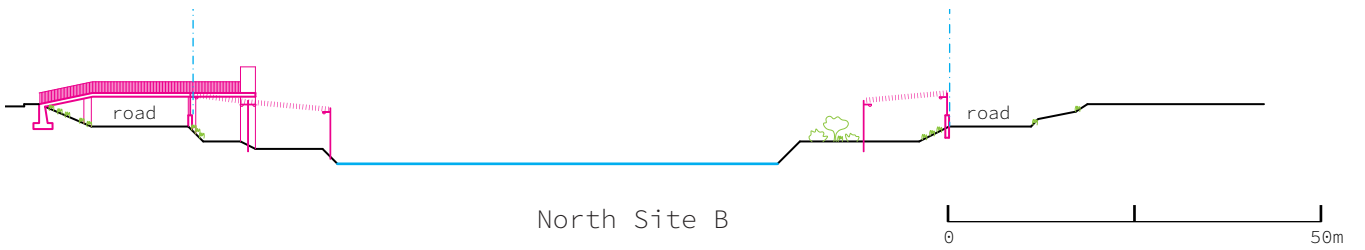
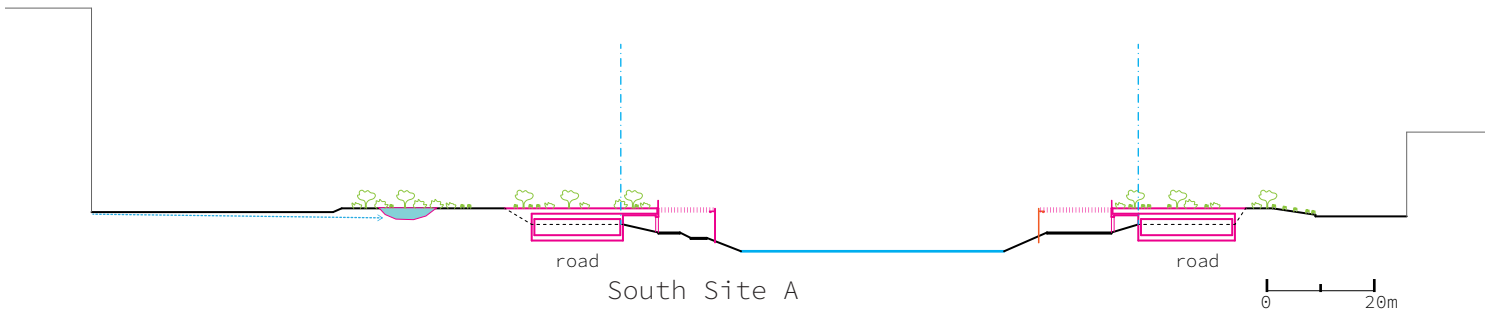
## Tan-1



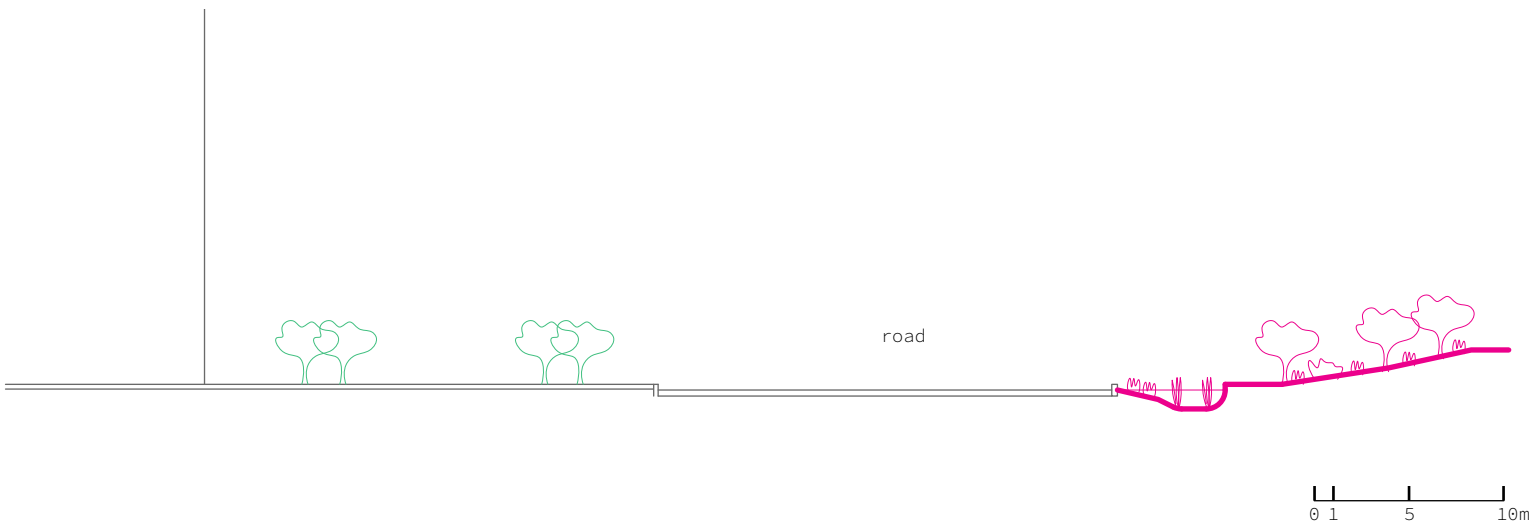
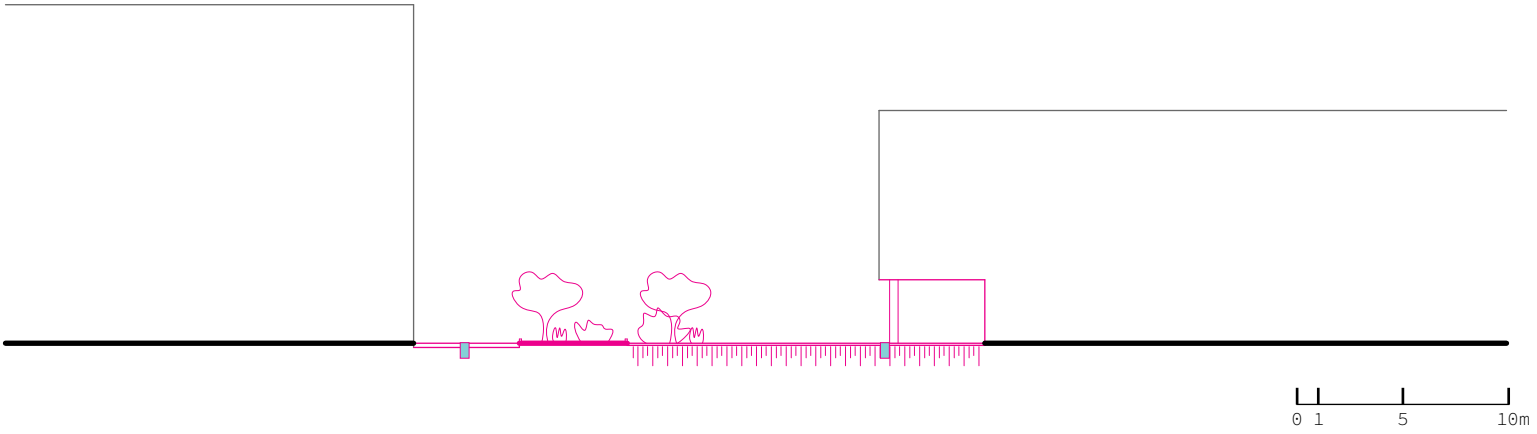
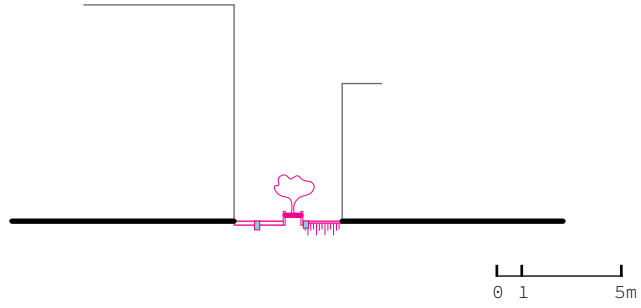
## Hongje-4



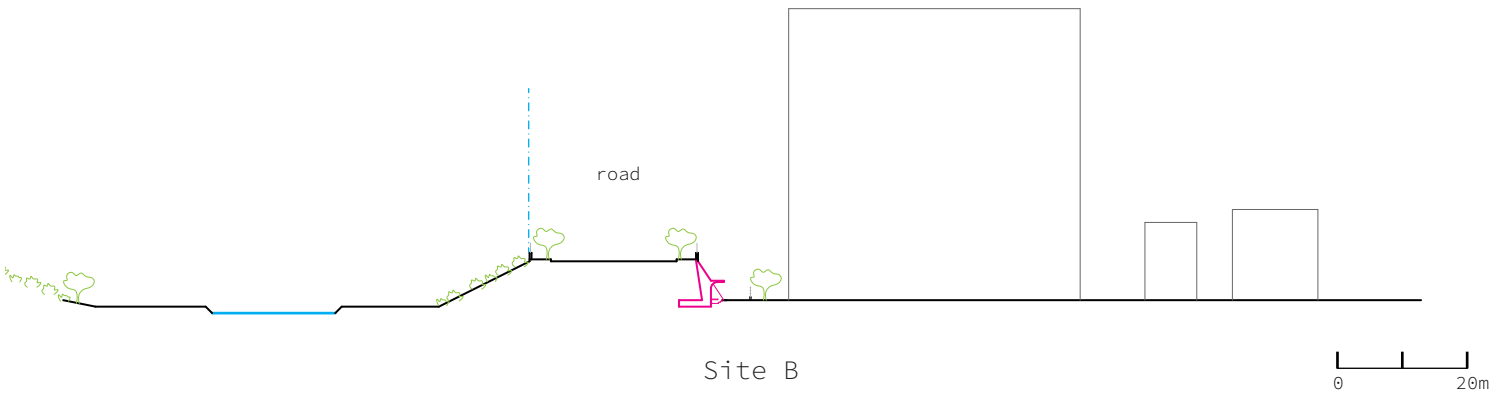
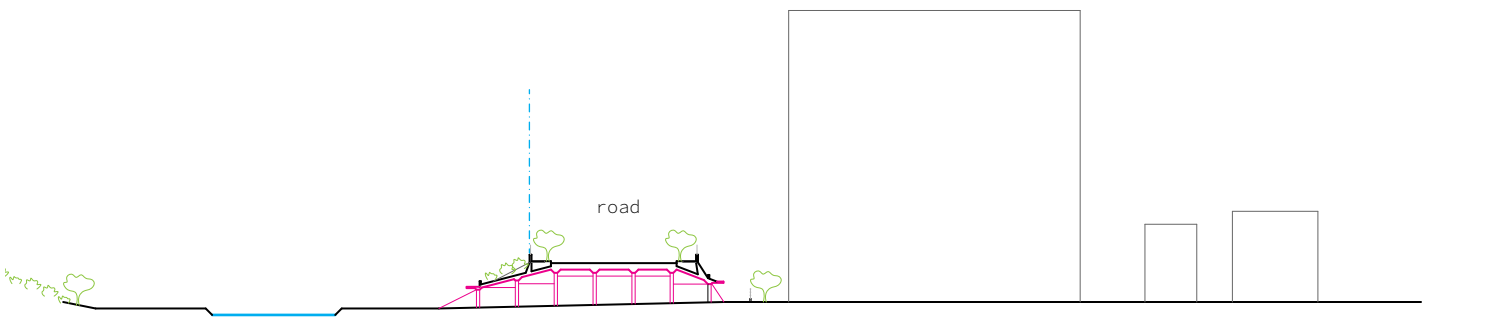
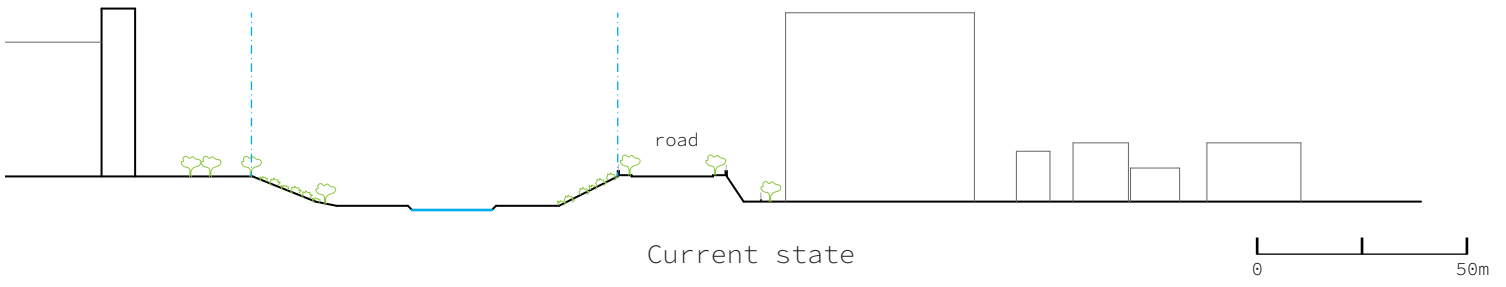
### Jungrnag-3



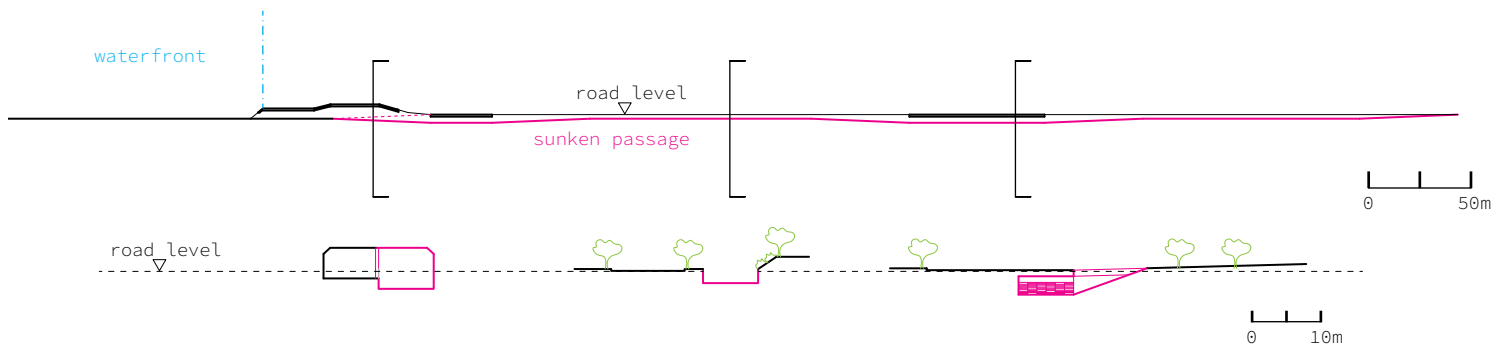
Jungrnag-3 / South / Site C



# Hongje-3

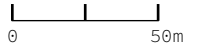
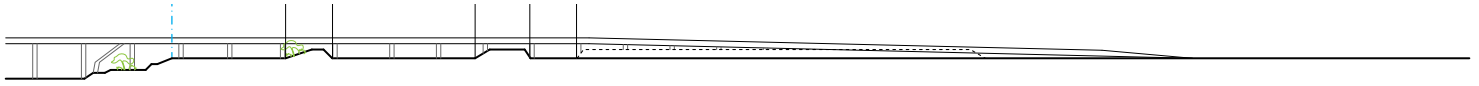


# Hangang -1S / West

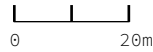
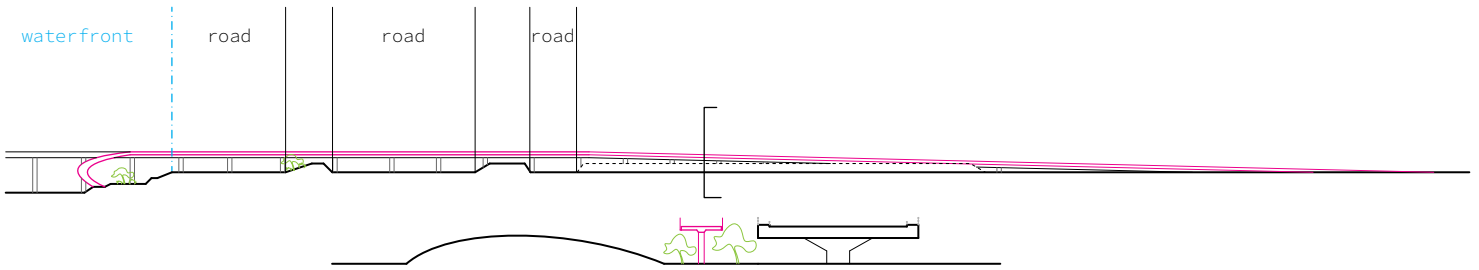


Site A

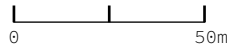
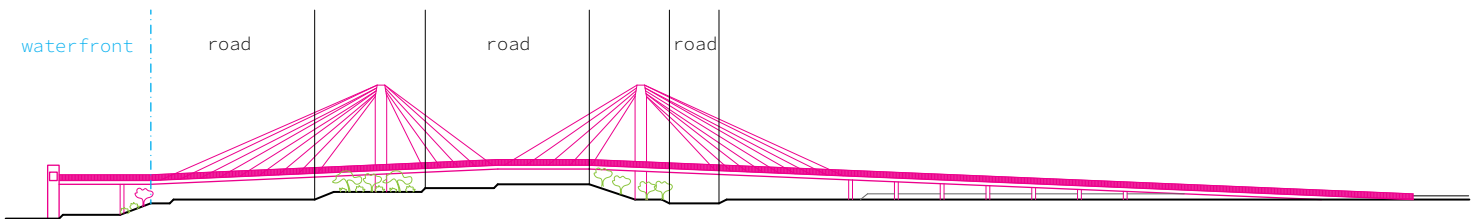
Hangang -1S / East



Site A Current state



Site A



Site B

## Appendix F : Design case studies

### Wadis in open spaces



Hikichi-gawa River Natural Waterscape Park

Hiramatsu, K., & Nakase, I. (Eds). (2002). Randsukēpu-to-ikuippunto: = Elements and total concept of urban equipment design. Graphic-sha Publishing Co.



Park City shin-Kawasaki

Elements & total concept of urban waterscape design. (1990). Graphic-Sha.



Ikebukuro Daisan Primary School Town Square

Elements & total concept of urban waterscape design. (1990). Graphic-Sha.



Stream Square, Showa Memorial National Government Park

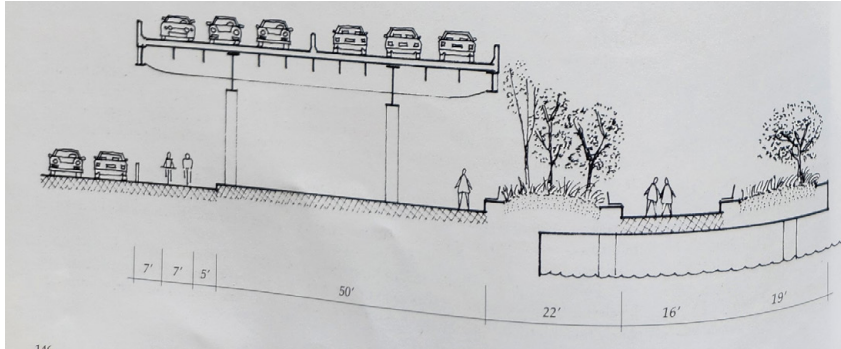
Elements & total concept of urban waterscape design. (1990). Graphic-Sha.



Biwajima Sports Center

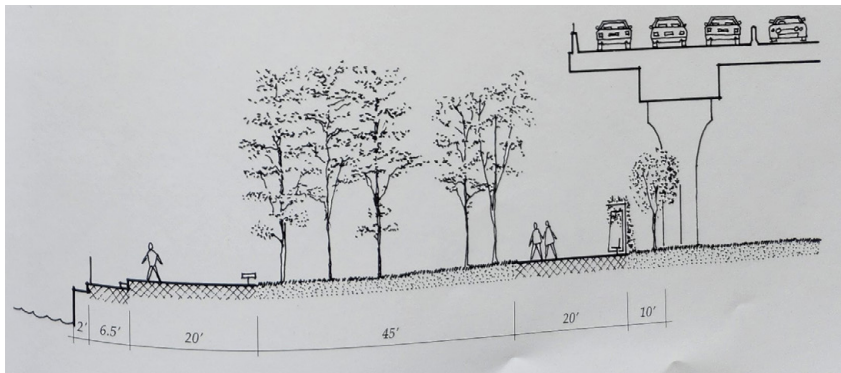
Elements & total concept of urban waterscape design. (1990). Graphic-Sha.

## Waterfronts near infrastructures



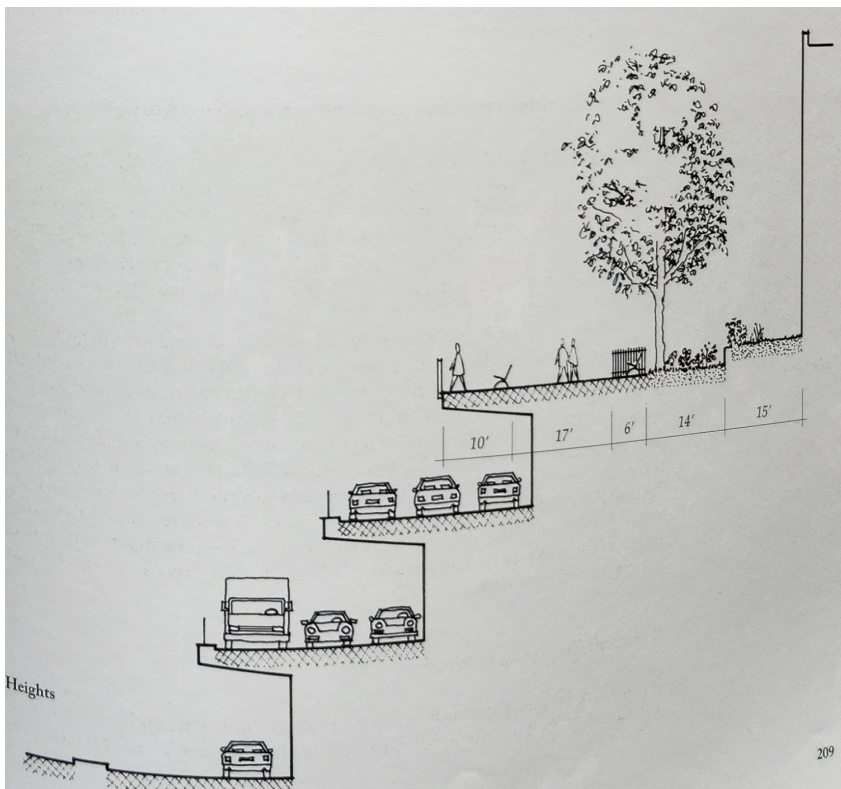
East River Waterfront Esplanade, NY, USA

Macdonald, E. (2017). Urban waterfront promenades. Routledge.



Kwun Tong Promenade, HongKong

Macdonald, E. (2017). Urban waterfront promenades. Routledge.



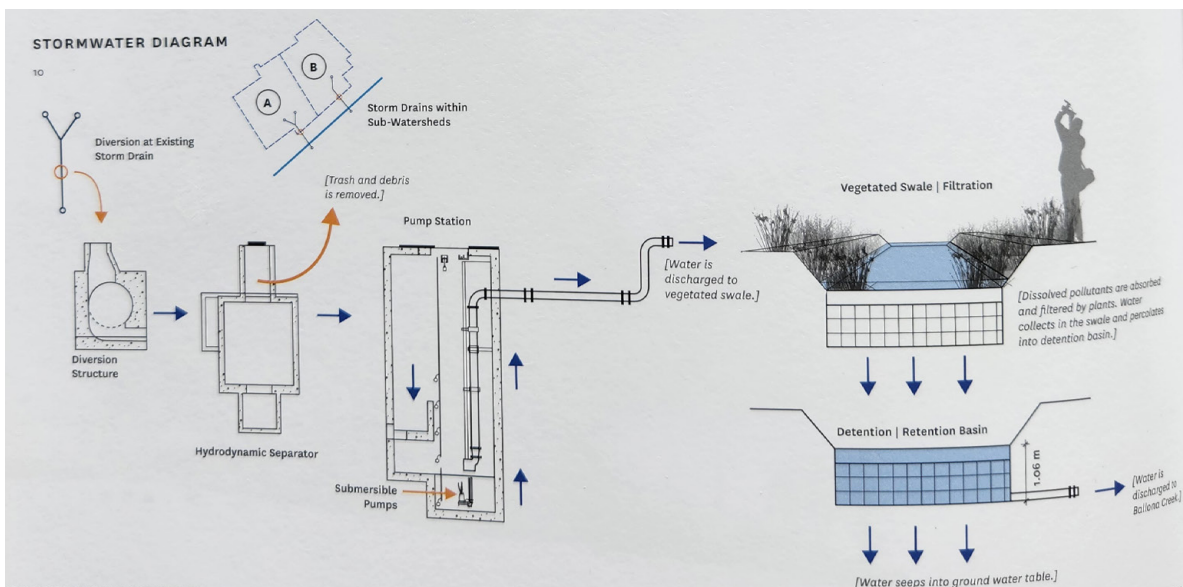
Brooklyn Heights Promenade, NY, USA

Macdonald, E. (2017). Urban waterfront promenades. Routledge.



Milton Street Park, LA, USA

Hung, Y.-Y. & SWA Group (Firm) (Eds). (2013). Landscape infrastructure: Case studies by SWA (2nd & rev. ed edn). Birkhäuser.



## Stormwater management



Camille Claudel Ecological District

Stormwater Management in Landscape Design. (n.d.). Design Media Publishing. (Original work published 2017)



1. The community square for residents



Infiltration tree basin detail  
 1. Permeable pavers used as gutters  
 2. Infiltration tree basin  
 Once infiltration tree basin exceed capacity excess stormwater flows to the gutter  
 3. Gutter

### Pigon Square Regeneration

Stormwater Management in Landscape Design. (n.d.). Design Media Publishing. (Original work published 2017)