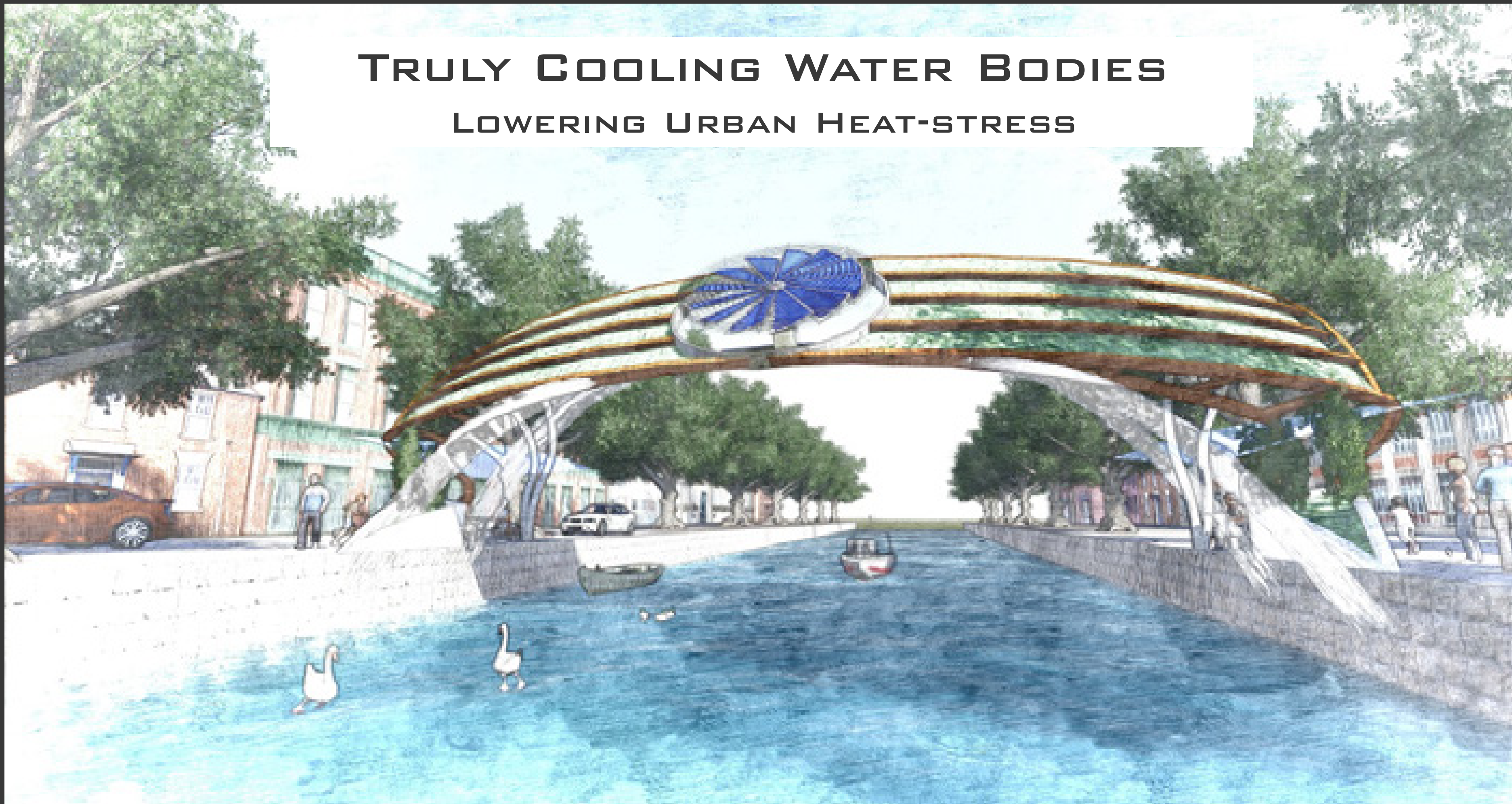
Truly Cooling Water Bodies

Lowering Urban Heat-stress



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Zhonglin Gao,
2017

This master thesis focuses on the “truly cooling water body” design which lowers urban heat-stress in residential areas in Dutch water cities during warm periods, using city Utrecht as an example.

Nowadays, the UHI (urban heat island effect) and global warming have made it more and more urgent to mitigate the urban heat-stress. Water retention for potential flooding has forced Dutch water cities to give more space to water and have more urban water bodies. In the past, designers thought water bodies cool down the environment. However water’s heat inertia makes it heating up the environment during the night in hot periods. It is necessary to design truly cooling water bodies.

The whole process of designing truly cooling water bodies follows an RTD (research through designing) process. The typical water bodies are identified in the intersections of residential and high heat-stress areas in Utrecht. They are then analyzed with their shadow and wind behaviors in hot periods.

Based on the analyses results, the design criteria are set for the design loops. The process of the design loops of this thesis is iterative, it goes from basic single designs to integrated designs. By combining and synthesizing, adding more evaluating criteria in the later design loops, refinement of the designs is achieved.

Finally, final design recommendations and design principles for representative water body types in the research areas are concluded from the design loops.

Key words: climate, Dutch water city, Utrecht, urban heat-stress, urban water body, truly cooling water body, RTD, design principle

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Chapter 1

Problem Addressing

1 Problem Addressing

As intense urbanization and global warming going on in Netherlands, urban heat-stress induced by Urban Heat Island (UHI) effect is going to be more severe in the near future (KNMI, 2014). This will result in more thermal discomfort and health problems, furthermore, higher mortality and lower work efficiency (Albers et al., 2012; Hove et al., 2011). Increasing extreme precipitation in Summer, and increasing general precipitation in the other seasons, also left “Dutch Water Cities” no choice but to have more water bodies retaining the peak precipitation.

In the past, urban planners and designers assume that water bodies cool down the ambient environment, mainly based on physical intuition, false common sense or superficial studies (Coutts et al., 2012; Hathway and Sharples, 2012; Kleerekoper et al., 2012; Oláh, 2012; Sugawara et al., 2009; Sun and Chen, 2012; Xu et al., 2010). Nevertheless, according to recent more precise researches, it is not always the case. During the evenings of Summer and even the whole days of early Autumn, the water bodies are actually warming up the environment (Saaroni and Ziv, 2003; Steeneveld et al., 2014; Theeuwes et al., 2013; Theeuwes et al., 2012).

This thesis focuses on the creating “truly cooling water bodies” for urban heat-stress mitigation in residential areas in “Dutch water cities” during warm periods, using city Utrecht as an example.

1.1 Global Climate Change in Netherlands

1.1.1 Urbanization in Netherlands

During the last few decades, intense urbanization and expansion of cities has been continuing in the world, as a result of constant population migration towards cities. As a WHO report says, the urban population in 2010 was up to more than half of the world population, and this proportion would increase to about 70% by 2050 (World Health Organization, 2014). At the same time, cities are gaining higher density (Hartig et al., 2014).

In the Netherlands, the situation is the same. In 2010, the Dutch urban population took up 82.9% of the total, and it is still growing (The World Bank, 2015). Furthermore, as shown on Illustration 1, urban areas evidently expanded during last few decades; and every urban area had expanded (Fazal et al., 2012). Consequently, a lot more natural surfaces were replaced by impervious man-made surfaces, both outside and inside the cities, modifying the urban climate (Ministry of Infrastructure and the Environment, 2011). A higher percentage of urban population means more people under the influence of urban climate, which puts more importance on urban climate.

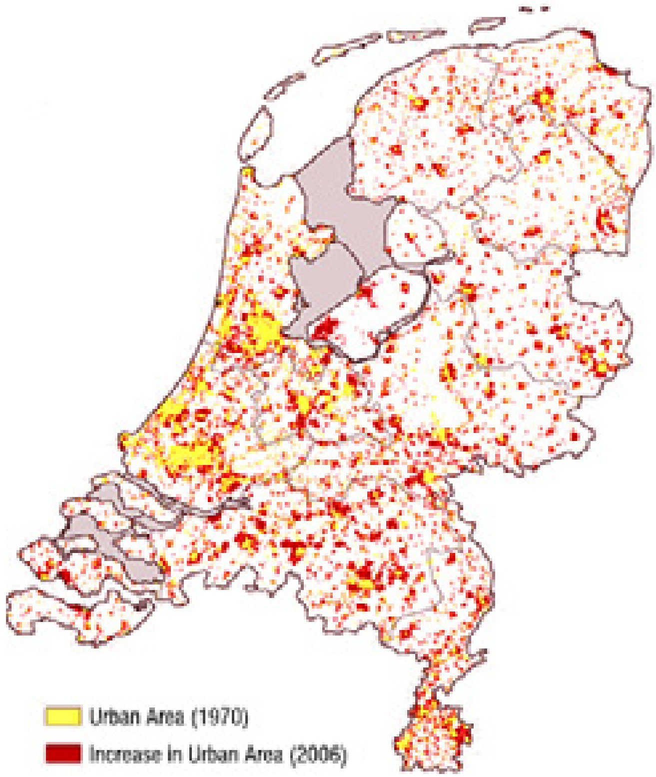


Illustration 1: The expansion of urban area in Netherlands during 1970 and 2006 (Fazal et al., 2012, based on GIS)

1.1.2 Global Warming & Precipitation Increasing in Netherlands

Since the beginning of the modern society, human interference with nature, including the radical urbanization, has induced the global climate change, especially the global warming, causing rise in temperature and patterns change in precipitation (IPCC, 2013). According to the Fifth Assessment Report of the UN Climate Panel, the Intergovernmental Panel on Climate Change, IPCC (2013), from 1880 to 2012, the global average surface air temperature data show a rise of about 0.9 °C; over the mid-latitude land areas of the Northern Hemisphere, average precipitation has increased since 1901.

According to Köppen climate classification, the whole Netherlands is under the Humid Oceanic Climate, which is quite mild (Köppen, 1931). Since the country is rather small, the climate condition throughout the Netherlands has little variations (WeatherOnline, 2015).

Illustration 2: The Köppen climate classification of Europe (http://www.printfree.cn/free-printable-maps-map-climate-zones-europe-printables307)

In the Netherlands, the Koninklijk Nederlands Meteorologisch Instituut (Royal Netherlands Meteorology Institute, KNMI) made the latest four climate scenarios for Netherlands in 2014 (Illustration 3). The KNMI'14 scenarios were created from the four combinations of two probable values for the global temperature rise, 'Moderate' and 'Warm', and two plausible changes in the air circulation pattern, 'Low value' and 'High value' (KNMI, 2014).

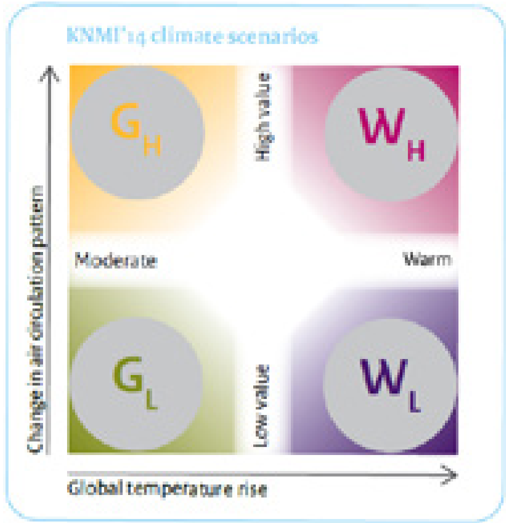


Illustration 3: The four climate scenarios KNMI made for Netherlands (KNMI, 2014)

On the temperature aspect, the Dutch situation is worse than the global (KNMI, 2014). Average temperature data in De Bilt (a representative weather station for Netherlands, which is also the closest to city Utrecht) increased by 1.8 °C between 1901 and 2013, about twice the global increase. All scenarios show temperature increase with no doubt (Illustration 4). In the "warmest scenario", W_H, it is predicted that by 2085, the number of heat waves will significantly increase; the number of hot summer days (days with max. air temperatures above 25 °C) will increase by 130%.

On the precipitation aspect, the annual precipitation between 1910 and 2013 has increased by 26% in the Netherlands; all seasons except summer have become wetter (KNMI, 2014). The average precipitation will increase throughout the year except for summer. In the relatively dry summer, intensity of extreme rain showers will increase. G_L and W_L show a small increase in average precipitation in summer, while G_H and W_H illustrate a considerable reduction.

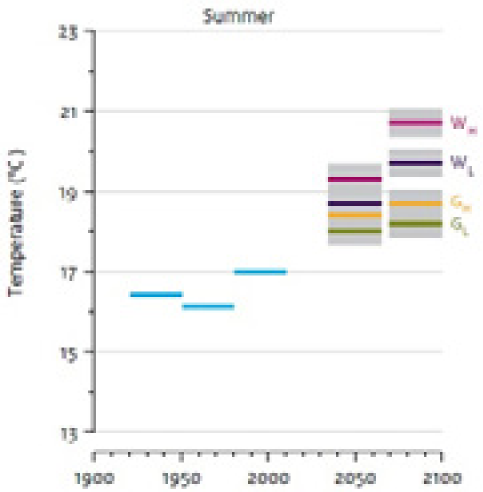


Illustration 4: Summer temperature in De Bilt (Netherlands): observations (three 30-year averages, in blue), KNMI'14 scenarios (2050 and 2085, in four colors) and natural variations (in grey). These are natural variations for 30-year averages. (KNMI, 2014)

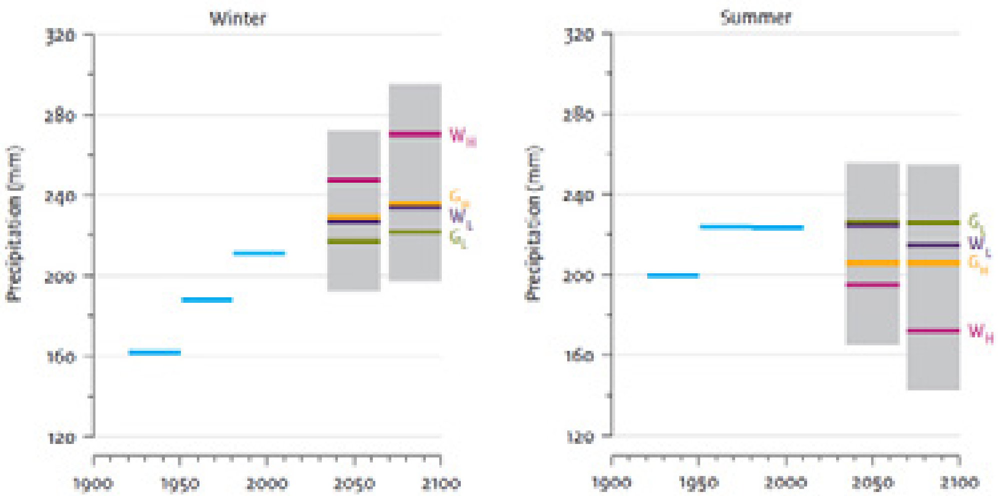


Illustration 5: Precipitation in the Netherlands: observations and KNMI'14 scenarios for 2050 and 2085 (KNMI, 2014)

1.1.3 UHI and Urban Heat-stress

The urban heat-stress condition in the Netherlands is probably getting worse as a consequence of global warming and the urbanization described in the sub-chapters above (IPCC, 2013; KNMI, 2014).

UHI effect combined with the heat wave from the global warming can produce tremendous heat-stress during warm periods, which negatively affects human well-being and the thermal comfort of the citizens, especially elderly people, young children and ailing people (Albers et al., 2012). Urban heat-stress has been correlated with the rise of urban mortality; it also reduces inhabitants' working and studying efficiency (Hove et al., 2011). Especially nocturnal heat-stress in residential areas inhibits citizens' sleep, causes health problems and low work productivity (Ihara et al., 2011; Moriyama and Matsumoto, 1988). With the majority of the population living in urban areas, and even more in the future, the situation urgently calls for the urban heat-stress mitigation.

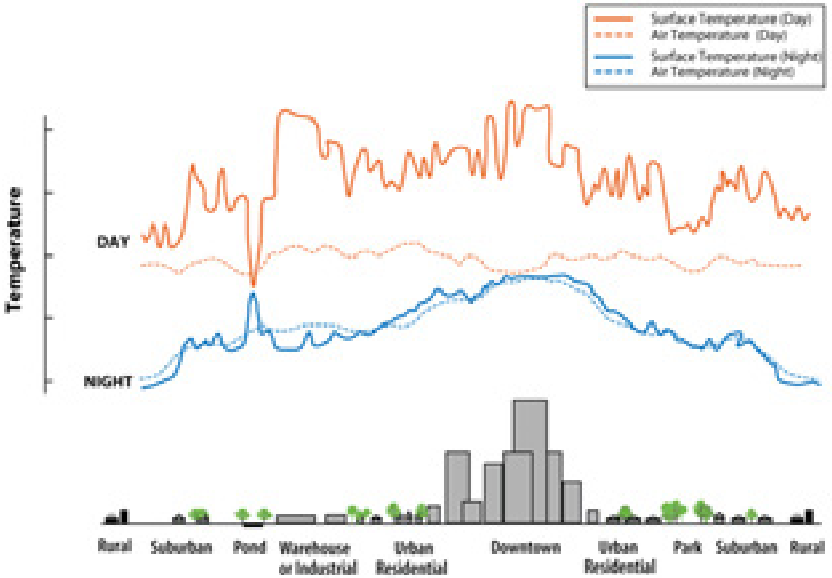


Illustration 6: The generalized UHI profile (http://www.epa.gov/heatisland/about/index.htm)

1.2 Urban Heat-stress in Dutch Water Cities

1.2.1 Dutch Water Cities

The scope of this thesis is on "Dutch water cities", referring to Dutch cities which have a history of being structured by water, and now still are.

As it is well known, Netherlands has a history closely related to water. According to Hooimeijer and Vrijthoff (2007, p.5), "the Netherlands was transformed in the period between 1100 and 1700 from a natural and ever-changing system of lakes, marshes, streams and rivulets into an advanced water management system." A lot of Dutch water cities were built and developed during that period of time usually with military (fortification), economic purposes, and water has been vital to the Dutch urbanization (Hooimeijer and Vrijthoff, 2007).

According to Hooimeijer and Vrijthoff (2007), in the Netherlands, these are the representative water cities: Alkmaar, Utrecht, Dordrecht, Leiden, Groningen, Leeuwarden, Amersfoort, Amsterdam, Delft, Rotterdam, 's-Hertogenbosch and etc. These Dutch water cities are relevant as the scope of this thesis because of the three factors: history, water and climate. Firstly, all these cities have a long history with water and highly historically valued areas with water structures, which is the same to Utrecht. Secondly, all the cities have a substantial amount of water bodies.

There are evidences proving that the urban heat-stress is severe in those Dutch water cities. According to Climate Adaptation Services (2015), the surface heat island (SHI, one of the types of UHI, which is indicated by the surface temperature) of all these Dutch water cities are quite obvious (Illustration 7 next page). These SHI maps indicate that the heat-stress during warm periods in these cities is quite high, which proves the heat-stress problem valid for the cities.

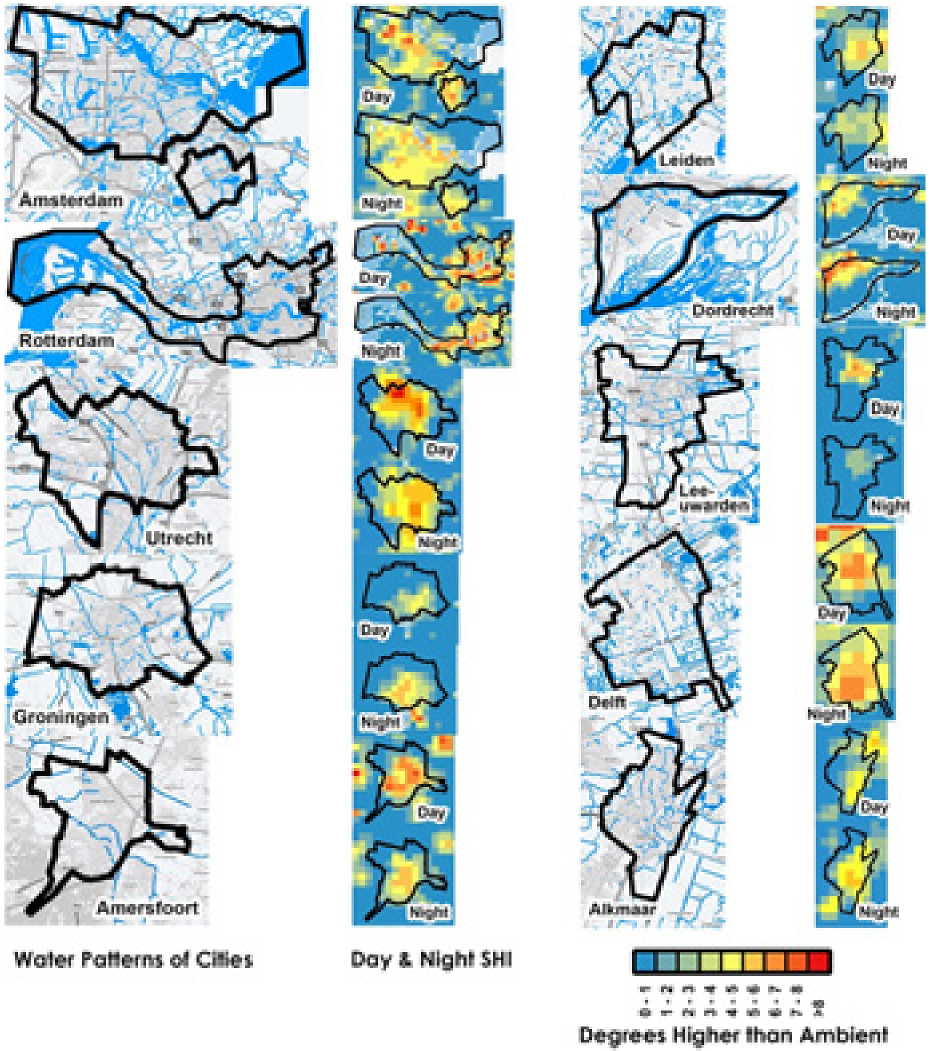


Illustration 7: The water patterns of the Dutch water cities, and the SHIs of them during both day (16 July 2006 12:07) and night (17 July 2006 02:04) (based on Climate Adaptation Services, 2015)

1.2.2 Urban Water Bodies in Netherlands

As the consequence of the changing precipitation pattern in Netherlands, there are water challenges for the Dutch water cities. Increased average and extreme precipitation means higher peaks of urban water bodies. In order to avoid potential floods, Dutch water cities need more space for water to improve the discharge and storage capacity of urban water bodies (Hooimeijer and Vrijthoff, 2007). For possible drought caused by relatively dry summer (KNMI, 2014), more stored water by more space can also mitigate it. This will lead to more water bodies in Dutch water cities.

But what does it mean to the urban heat-stress in Dutch water cities? In the past, designers and planners assume that urban water bodies can be considered as the cooling tool in the urban environment, mainly based on physical intuition or common sense (Coutts et al., 2012; Hathway and Sharples, 2012; Kleerekoper et al., 2012; Oláh, 2012; Sugawara et al., 2009; Sun and Chen, 2012; Xu et al., 2010). However, water's large heat capacity determines its heat inertia. Recent researches show that it also emits a lot of heat when it stores much of heat, aggravates the heat-stress during the nights of the warm periods, or even during the days in late summer or early autumn when the water bodies are with quite high temperature (Saaroni and Ziv, 2003; Steeneveld et al., 2014; Theeuwes et al., 2013; Theeuwes et al., 2012). It can be concluded as the two-sided thermal effect, the urban heat-stress mitigation and aggravation of water. Given the reality that Dutch water cities which need more urban water bodies, they are facing greater heat-stress in the aggravated situations than other cities, and will face more.

1.3 Utrecht as a Representative

Utrecht is one of the typical Dutch water cities, also one of the Dutch cities that had expanded and condensed noticeably (Illustration 8). According to the municipality of Utrecht (Schenkels and Hendriks, 2014), during the last two decades, the population of Utrecht grew from about 200,000 to about 300,000; and the average green area per household is lower than other Dutch cities (Illustration 9). Larger population in Utrecht also increases the consequence of the urban heat-stress.

Illustration 8: the city expansion of Utrecht (Schenkels and Hendriks, 2014)

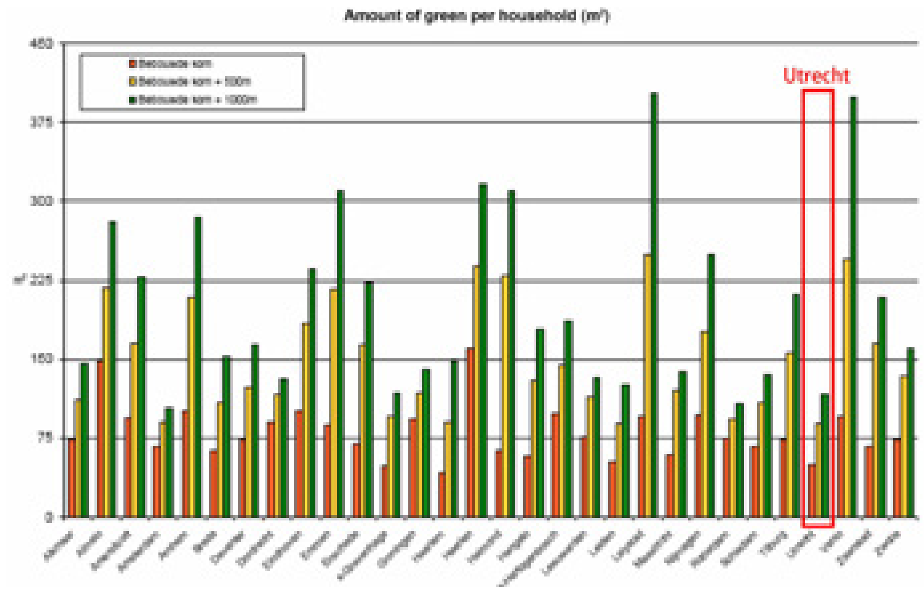


Illustration 9: Amount of green area per household of Utrecht (Schenkels and Hendriks, 2014)

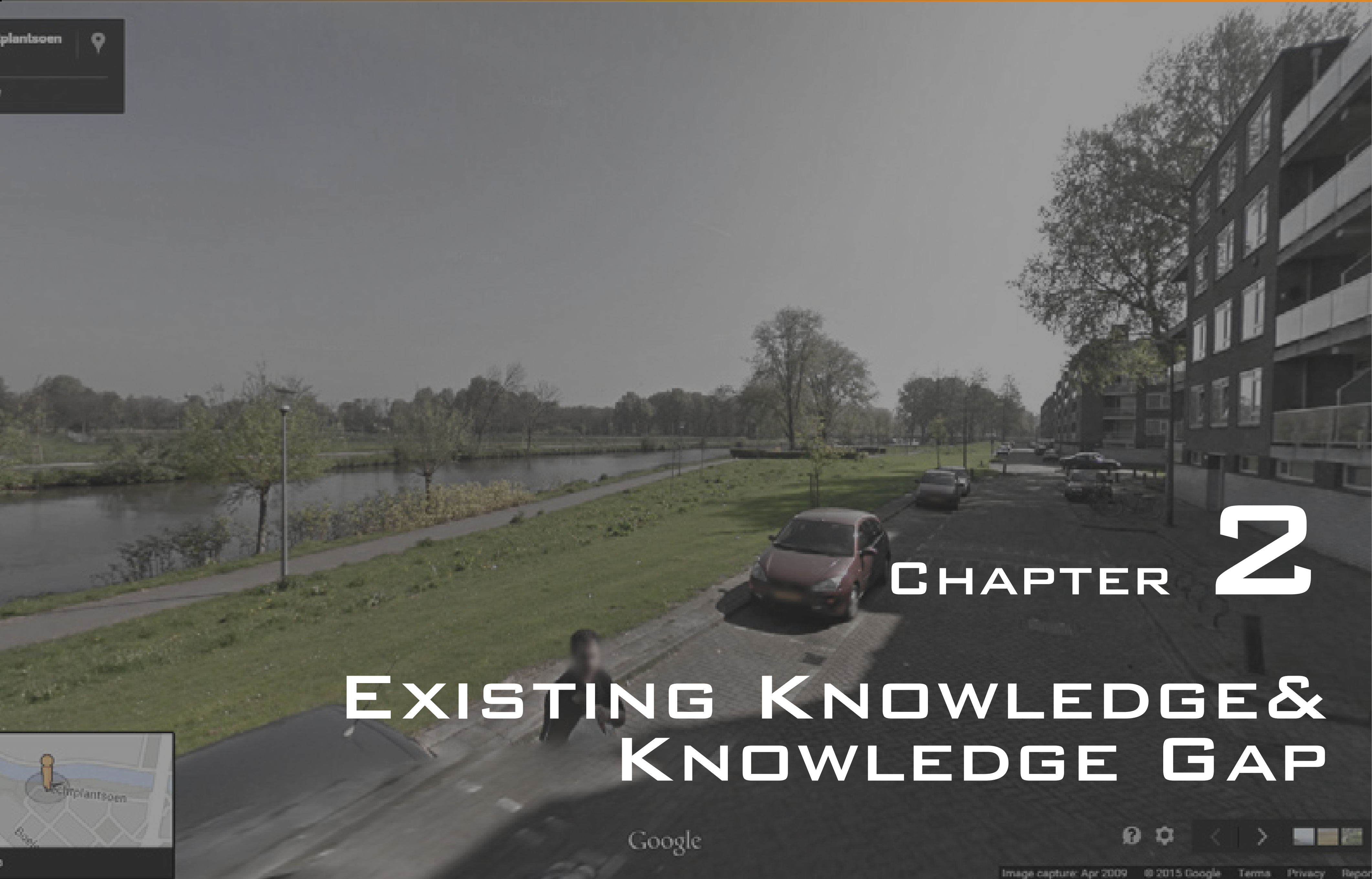
1.4 Problem Statement

To conclude, because of the global warming and the urbanization, the intensity of the UHI in Netherlands is rising (KNMI, 2014). Thus, the urban heat-stress in the Dutch water cities is getting higher and higher.

Furthermore, changed precipitation pattern cause a bigger need for water retention space in Dutch water cities (Hooimeijer and Vrijthoff, 2007). This leads to more water bodies. However, urban water bodies have both cooling and warming effect (Saaroni and Ziv, 2003; Steeneveld et al., 2014; Theeuwes et al., 2013; Theeuwes et al., 2012).

Urban heat-stress can negatively affect citizens' well-being and thermal comfort, which lead to the increase of mortality and the decrease of efficiency (Albers et al., 2012; Hove et al., 2011). Moreover, nocturnal heat-stress which can be aggravated by water bodies inhibits sleep of citizens, hence cause health problems and low diurnal productivity (Ihara et al., 2011; Moriyama and Matsumoto, 1988).

With the large populations living in the Dutch water cities, and even more in the future (The World Bank, 2015), it is urgent to create "truly cooling water bodies" especially in the residential areas where citizens sleep.



Chapter 2

Existing Knowledge & Knowledge Gap

2 Existing Knowledge & Knowledge Gap

The existing knowledge about urban heat-stress, and the methods to mitigate it are already substantial. They are reviewed in a literature study in this chapter. The relevant knowledge is identified, and the knowledge still scarce to create truly cooling water bodies is identified as the knowledge gap.

2.1 UHI, the Types and Scales

According to Erell et al. (2011), the UHI effect is one of the most significant phenomena of the urban climate. The definition of UHI according to them is that, under certain weather condition, the surface and air temperature of urban areas are higher than the surrounding rural areas. Surface temperature differences form the surface heat island (SHI); while the air temperature differences form the atmospheric heat island (AHI).

UHI does not only have different types, but also influence on different urban scales. Hove et al. (2011) defined three scales of UHI based on Oke (1997) (Illustration 10). Different scales also have their own characteristics and focus. This thesis fits the micro scale, which is street canyon scale. It goes to the street trees, shrubs and lawns, water bodies, pavements, building surface materials, width/height ratio of the canyon, detailed air movements, the shadow pattern, etc.

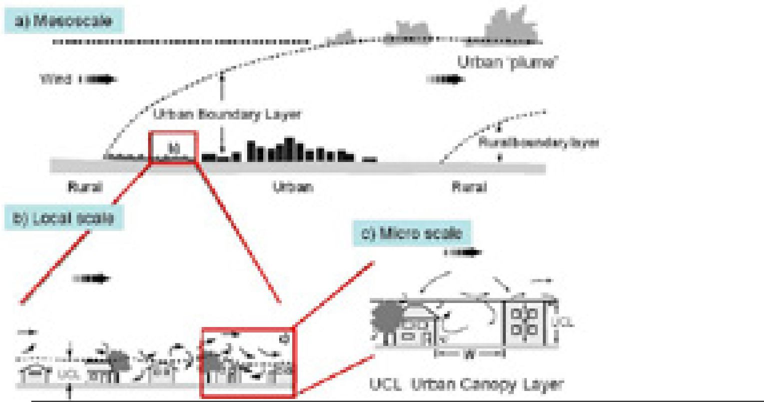


Illustration 10: Three scales of UHI (Hove et al., 2011) based on (Oke, 1997)

2.2 Underlying Causes of UHI

Urbanization replaces the natural surfaces with built, impervious, stony surfaces, compact urban fabric which leads to the heat-stress in the urban areas by mainly three reasons (Brown and Gillespie, 1995; Erell et al., 2011; Oke, 1987):

- Firstly, the built up areas are usually made of artificial materials and structures which usually have lower albedo and smaller heat capacities than natural elements, they can be easily heated up with high surface temperatures, hence heat up the whole area. While natural area is shaded by trees;
- Secondly, a vegetated area is cooled down by shading and evapotranspiration (the transpiration of vegetation is much greater if it is with enough water source), while urban area evaporates much less due to the fast urban drainage system and impermeable and non-water-storing surfaces;
- Thirdly, the complex spatial geometry of the compact urban fabric traps the heat and stems the ventilation (for instance sun radiation is completely absorbed after a few reflections in a narrow street canyon, and the city plans are seldom concerned with the natural ventilation), make heat stay within urban area, while natural area is usually with relatively open space and better ventilation;
- The other factors include the anthropogenic heat, local climate, etc.

2.3 Mechanism of Urban Heat-stress Mitigation

From the underlying causes of UHI, it can be concluded that the factors influencing the temperature difference between urban and natural surfaces are mainly shading, evapotranspiration and ventilation.

2.3.1 Shading S in Urban Heat-stress Mitigation

Shading's cooling mechanism involve two thermodynamic processes: one is transferring and storing energy from radiation in a non-heat state (photosynthesis), the other is reflecting radiation. It is preventing radiation heat from being completely absorbed by the shaded area and the shading material.

For common materials, only reflecting is happening, the other radiation energy will just be stored as heat in the material and later transmitted to the environment if the material's temperature is higher. For vegetation, the sunlight (sun radiation) can be transferred (photosynthesis) to non-heat energy (Erell et al., 2011).

Sunlight is the main heat input of the environment (Brown and Gillespie, 1995; Erell et al., 2011; Lenzholzer, 2013; Oke, 1987), shading is the prime method in the heat-stress mitigation.

2.3.2 Evapotranspiration E in Urban Heat-stress Mitigation

The heat in our environment is divided into "sensible heat" and "latent heat" in thermodynamics. If the heat exchange does cause a temperature difference, it is referred to as "sensible heat". If the heat exchange happens during the transition between the liquid and vapor state of a substance, which does not make a temperature change, it is referred to as "latent heat". In the environment, water vapor is the most common form of latent heat carrier(Brown and Gillespie, 1995; Erell et al., 2011; Oke, 1987).

Evapotranspiration is exactly the process of transferring the sensible heat into latent heat. It is relevant to heat-stress mitigation because it is reducing the heat that can be felt by people, and cooling down the environment.

2.3.3 Ventilation V in Urban Heat-stress Mitigation

Wind, the air movement, is usually induced by the uneven heating of the atmosphere; as the air is heated, it expands, rises, and is replaced by cooler air; and the iteration of the process creates the general circulation, the major wind system of the earth, which is also usually the cause of the prevailing wind of one region (Boutet, 1987; Brown and Gillespie, 1995). This process is defined as convection of air by Oke (1987), which also includes the reversed situation, the cooler air tends to shrink and sink, gets replaced by warmer air, and so forth. The air convection is a very important phenomenon to urban heat-stress mitigation, because it efficiently transports both sensible heat and latent heat (Brown and Gillespie, 1995; Oke, 1987). Convection wind happens both on the regional scale and local scale.

Ventilation refers to the process of refreshing the air of a certain space. It naturally happens when there is air convection. It carries away both sensible heat and latent heat in the air. (Kleerekoper et al., 2012; Krautheim et al., 2014; Yokohari et al., 2001).

Evapotranspiration is cooling down the environment by turning water into water vapor. If water vapor transits into water again, the latent heat is going to be released into sensible heat again. Also the evapotranspiration will be slowed down if the air is saturated by water vapor. So it is very vital for ventilation to blow the water vapor away and bring in fresh drier air (Brown and Gillespie, 1995; Erell et al., 2011; Oke, 1987).

2.4 Green & Water in Urban Heat-stress Mitigation

Vegetation, green, can transfer and reflect radiation by shading; cool down the ambient by evapotranspiration, and the effect of which is very dependent on the availability of water (Erell et al., 2011; Gober et al., 2009; Kleerekoper et al., 2012). Nevertheless, it stems the ventilation if the trees and shrubs stand in the way of the wind. Green's cooling effect has been confirmed by many researches (Dimoudi and Nikolopoulou, 2003; Oke et al., 1989; Takebayashi and Moriyama, 2009; Theeuwes et al., 2012; Wilmers, 1988).

Based on all the literatures, the relations among green, and the cooling mechanisms can be illustrated as:

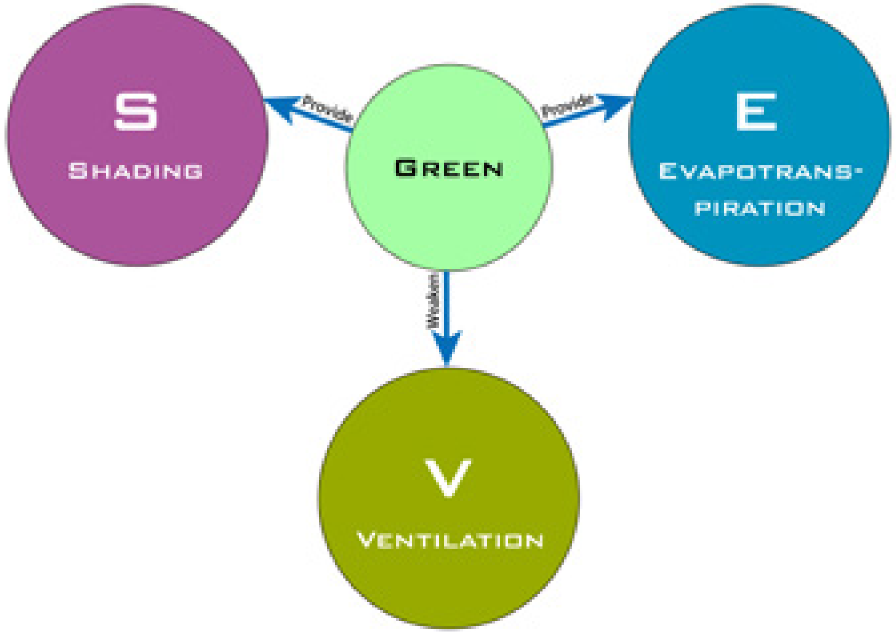


Illustration 11: The relations among the green, and cooling mechanisms

When green is beside water, they have interactions on cooling. Green enhances the evaporation of water by evapotranspiration, and cools down water by shading. On the other way, water supports the evapotranspiration of green by offering unlimited water. Besides, water increases green's amount, since vegetation spontaneously grows nearby water bodies (Kleerekoper et al., 2012).

The relations among green, water and urban heat-stress, can be illustrated as:

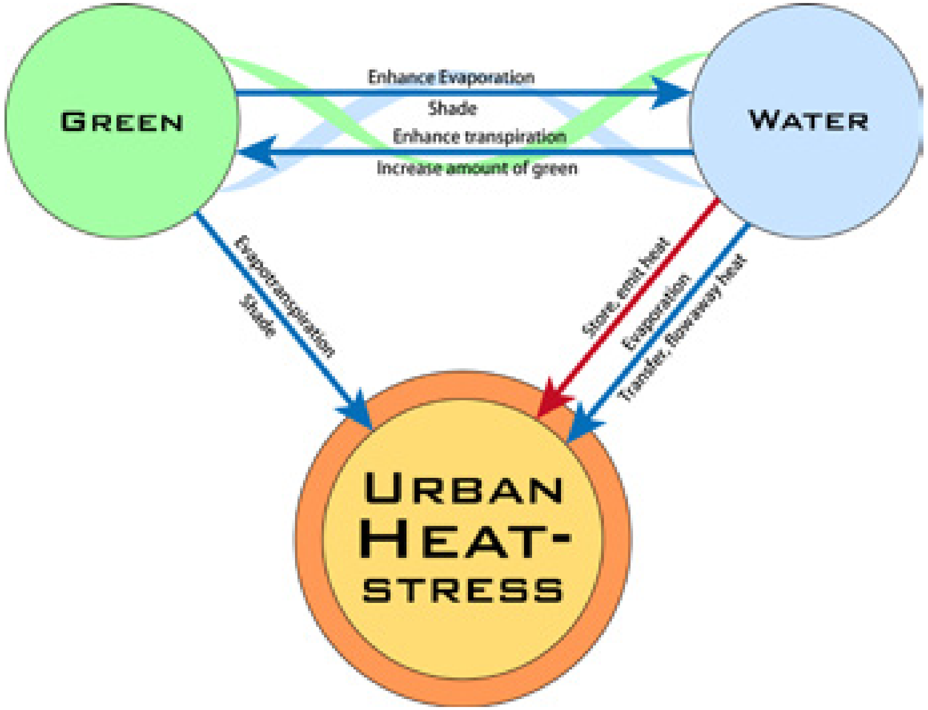


Illustration 12: The relations among the green, water and urban heat-stress

Ventilation wind is the heat exchange media of the green and water and the surrounding environment. The ventilation wind heat exchange situation in a typical urban street canyon with green and water is:

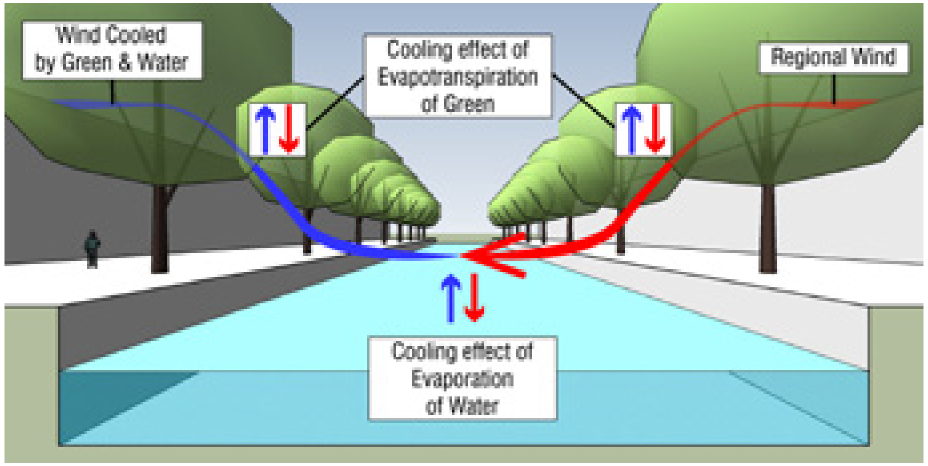


Illustration 13: The heat exchange effects of ventilation wind concerning green and water

2.5 The Knowledge Gap

Based on the existing knowledge, three cooling mechanisms are identified: shading, evapotranspiration and ventilation. So is the fact that green has the combination effects of shading and evapotranspiration. However, the mechanisms are logical deducted from the existing literatures, it is not directly concluded from any literature.

Theoretically, the three mechanisms are also not completely compatible. The cooling effect itself is lowering the temperature of water, which according to the physical law: “the lower the temperature, the slower the evaporation”, will slow down evaporation. The same applies to transpiration, in lower temperature plants transpire less. The saturation of water vapor in the air is also influencing both evaporation and transpiration. The higher the saturation, the slower the evapotranspiration. Thus, shading is lower the temperature of water, hence stemming evapotranspiration. And the objects which cast the shadows are likely to become obstacles for ventilation. Basically, evapotranspiration is just slowing down itself because it is both lowering the temperature of water and saturating the ambient air with water vapor. Ventilation is, however, encouraging evapotranspiration by blowing away water vapor. The relations amongst the three mechanisms are:

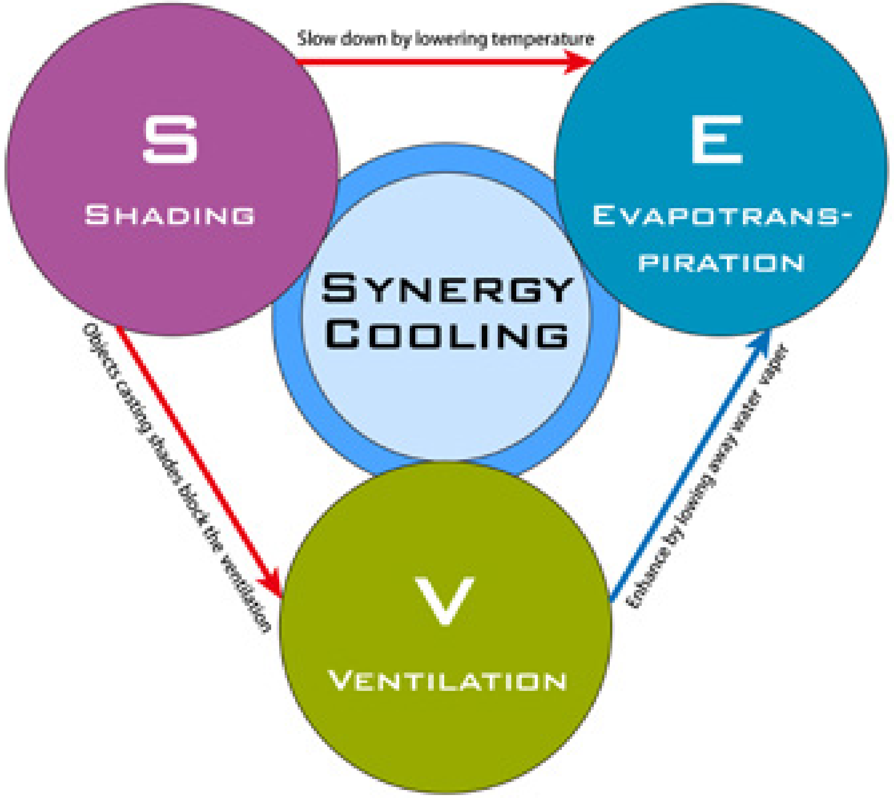


Illustration 14: The relations amongst the cooling mechanisms

The ideal situation should be the maximizing of the cooling effect of each single mechanism. And when combined, the weakening of each others is minimized, to reach the max. synergy of the single cooling effects.

Under detailed situations, different methods of the three cooling mechanisms should be explored. How the spatial effects of the interventions are, and how the real cooling effects are under certain situations, are not known to us neither. Not to mention the knowledge of maximizing the synergy of the cooling effects of the three mechanisms is scarce. Even besides the knowledge of the cooling effect, the spatial impact of the cooling methods on social and functional aspects is unknown.

So the knowledge gap lies in the methods of creating truly cooling water bodies, and how the real spatial impact is on cooling effect, and feasibility aspects.

2.6 Research Questions

The knowledge gap leads to the research questions. The main research question would be:

- What design types can truly cool water bodies in residential areas to mitigate urban heat-stress?

The sub-research questions would be:

- What are relevant types of water bodies in high heat-stress residential areas?
- Under what criteria can these types of water bodies be designed to become truly cooling water bodies?
- In what research-design process can truly cooling water body design principles be generated?

Chapter 3

Research through Designing (RTD)

The main purpose of this research is to explore the possibility of mitigating the urban heat-stress in residential areas through landscape architecture and urban designing of urban water bodies. In order to do that, the typical forms, situations of water bodies in city Utrecht (Test-beds) will be identified, and be used as examples. The whole process include the preparation (Test-beds identification) and a RTD process (Lenzholzer et al., 2013), which will be explained at length in this chapter. In the end, the design principles of truly cooling water bodies in residential areas in Dutch water cities will be generated.

3.1 Research-Design Strategy and Methods

The strategy is basically based on the validation of the generalization and transferring of representative cases, and research through designing (Lenzholzer et al., 2013). The detailed strategies and methods for the sub-research questions can be found in the following table:

Research-design stage	Sub-research question	Research methods	Research-design relation
Test-beds identification stage	What are relevant types of water bodies in high heat-stress residential areas?	**Data collection** • Function zones of Utrecht • Water body map of Utrecht • Climatope map of Utrecht **Data analysis** • Overlap maps of climatope and water bodies of Utrecht around residential areas • Specify typical forms and situations of water bodies in high heat-stress residential areas in city Utrecht, as test-beds • Average detail measurements of test-beds (systematic sampling) **Data interpreting** • Concretely fix-scaled test-bed models	Research for design

Research-design stage	Sub-research question	Research methods	Research-design relation
Design Criteria identification stage	Under what criteria can these types of water bodies be designed to become truly cooling water bodies?	**Data collection** • Shadow situation of test-beds • Wind information of Utrecht **Data analysis** • Overlap the shadows of the peak hours (10-16) of radiation and identify the areas exposed the most in test-beds • Apply the wind situation of Utrecht to the conditions of test-beds and confirm the detailed wind behaviors • Apply three cooling mechanisms to the detailed situations of test-beds **Data interpreting** • Conclude criteria of designing truly cooling water bodies from the applied cooling mechanisms	Research for design
Design Loops stage	In what research-design process can truly cooling water bodies design principles be generated?	**Iterative designs & tests** • Sketch possible basic designs based on the criteria • Choose promising basic designs and apply to all the test-beds • Critically evaluate designs according to criteria with experts • Refine criteria by reflecting on the evaluations • Combine basic designs for test-beds • Critically evaluate again with refined criteria and added feasibility criteria • Improve combined designs according to refined criteria and feasibility criteria to create final designs • Conclude design principles from refined final designs • Final evaluation and reflection	Research through designing

Illustration 15: Detailed research-design strategy steps and methods

3.2 Flow Diagram of RTD Process

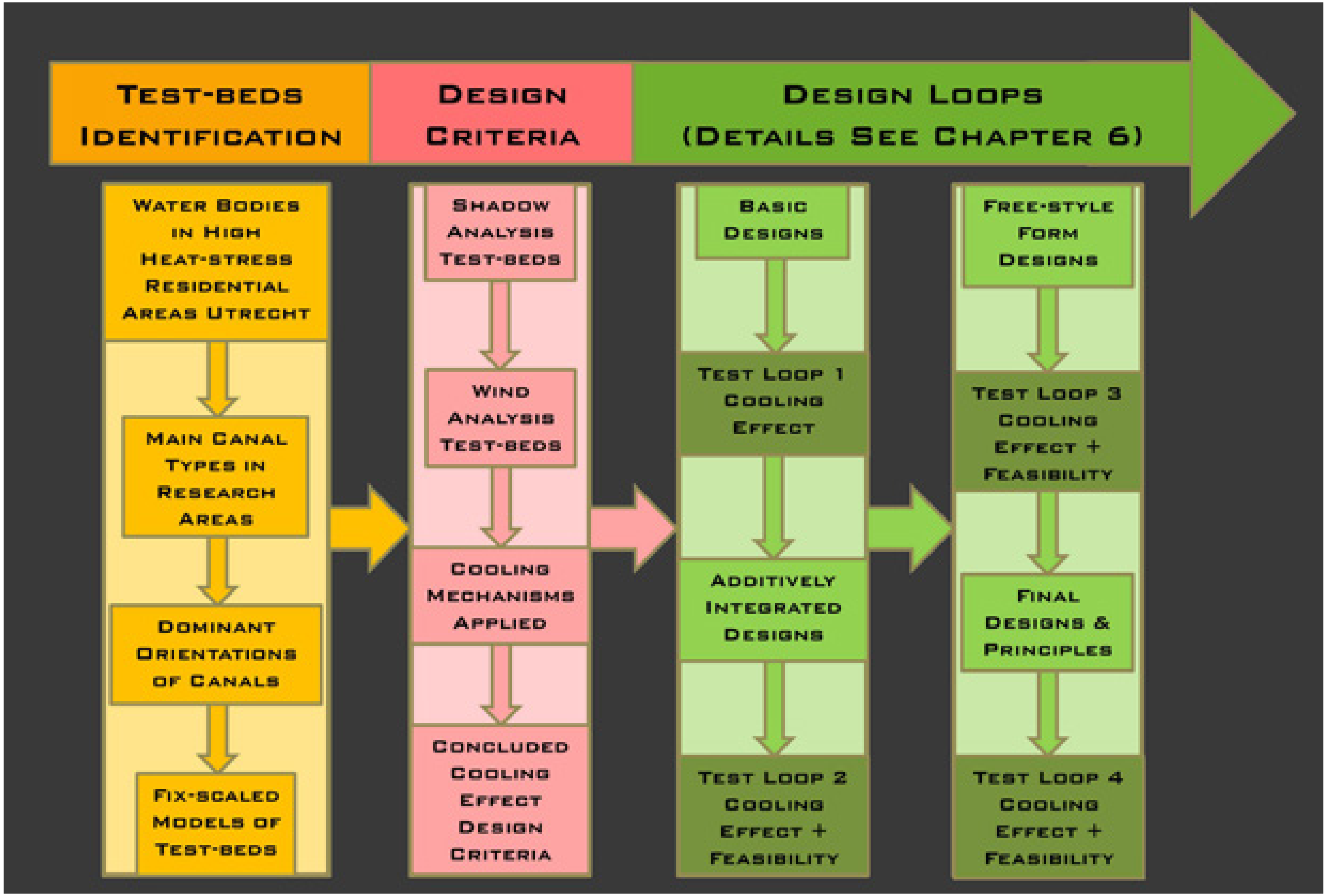


Illustration 16: The diagram of RTD process

In Illustration 16, the steps of the research-design process are visualized. The whole process is divided into 3 stages: test-beds identification, design criteria identification, and design loops. Amongst them, the first stage is the preparation of the RTD process. The second stage is the theory application. The last stage is the RTD main stage, the essence of this thesis.(Cross, 2004; Lenzholzer et al., 2013).

In the test identification stage, firstly, locations of test-beds are narrowed down by specifying the water bodies in the residential areas. And by overlapping the climatope map, it is further narrowed down to water bodies in the intersections of high heat-stress areas and residential areas. Then it can be found that in Utrecht residential areas all the relevant water bodies are canals. Dominant canal profile types and orientations are identified after that, to find the representative water bodies. According to those factors, final chosen test-beds are identified. Detailed average scales of the test-beds are calculated based on measurements of the systematic sample points. In that way, concretely fix-scaled test-bed models are made.

In the design criteria identification stage, detailed shadow simulations can be operated according to the geographical location of Utrecht, dates of the hot periods, time points of the hot hours during the day. Similarly, detailed wind analysis is done according to the regional prevailing wind situation in Utrecht in hot periods. According to the interpretation of detailed shadow and wind behaviors in the test-beds, the three cooling mechanisms: shading, evapotranspiration, and ventilation can be theoretically applied accordingly to test-beds' situations. Hence, the initial design criteria of cooling effect are identified for test-beds, to direct the first design loop, and to be refined through design loops.

In the design loops stage, there are generally 4 iterative design-test loops. In Loop 1 Basic Designs, single method interventions are designed for each test-bed according to the cooling effect criteria. The actual cooling effect of them with their spatial characteristics are evaluated with experts. The criteria of cooling design are also refined through reflection. In Loop 2 Additively Integrated Designs, the most effective method on each mechanism is systematically selected for each test-bed, and creatively integrated in order to maximize their synergy on cooling. They are then again evaluated on the actual cooling effect. The criteria are further refined. But this time, the feasibility criteria concluded from the profiles of the test-beds are also introduced into the evaluation. In Loop 3 Free-style Designs, creative forms of representative Additively Integrated Design are explored, to extend the options of form giving of the Additively Integrated Designs. The cooling effect and feasibility are also evaluated for the Free-style Forms. In the Final Loop, chosen Free-style Form and Additively Integrated Designs are combined to create a final design for representative test-beds. They are tremendously improved especially in terms of feasibility. The design principles are concluded for each test-bed, which represent a series of canals. And the they are finally evaluated and reflected.

Chapter 4

Test-beds Identification

To articulate which kinds of water bodies are vulnerable to urban heat-stress, certain factors that must be considered. Firstly, the location, they must be in high heat-stress residential area. Secondly, the types, the profiles of water bodies are various, the profiles (arrangements of houses, roads, green, water bodies) that are typical and representative must be identified under reasonable criteria. Thirdly, the orientation is vital to the detailed analysis of shadow and wind behaviors, which is the fundamentally necessary analysis of microclimate for heat mitigation (Brown and Gillespie, 1995; Lenzholzer, 2013; Oke, 1987). With these three factors confirmed, the relevant test-beds can be identified.

4.1 Location of Test-beds

GIS data of Utrecht were used to identify function zones and water bodies in Utrecht. Illustration 17 shows the residential area and water bodies of Utrecht:

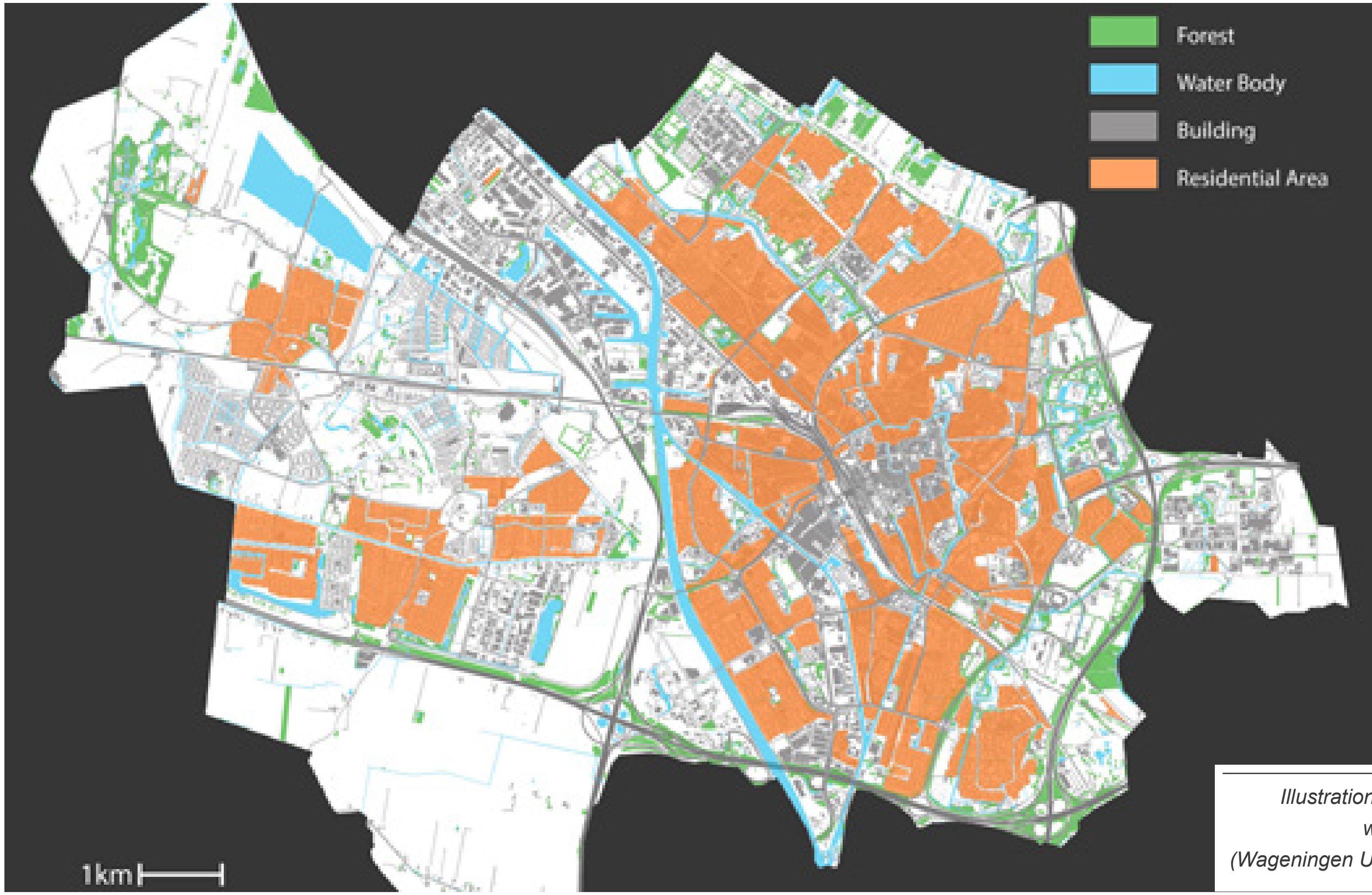


Illustration 17: Residential area and water body map of Utrecht (Wageningen University GIS Data, 2015)

For locating test-beds, climatope of Utrecht is used to locate high heat-stress areas. The concept of a climatope map is that a map which contains different zones with specific microclimatic characteristics. The microclimatic characteristics are commonly determined by building forms, ground pavements, vegetation, water bodies, human activities, etc. (Lenzholzer, 2013). And according to Etteger et al. (2014), the climatope of Utrecht is demonstrated as:

The areas that are in red and dark red are under high heat-stress during the hot periods.

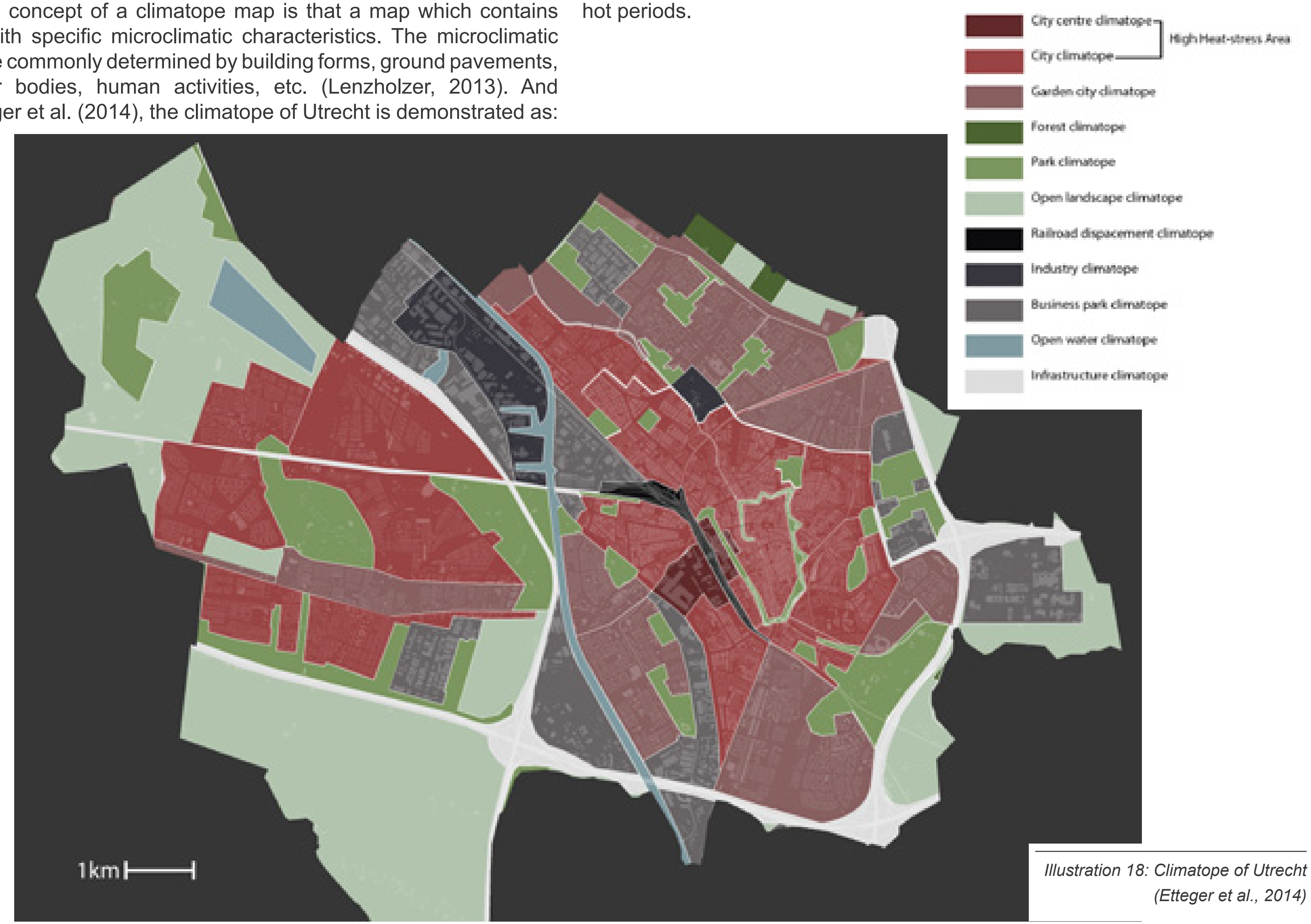


Illustration 18: Climatope of Utrecht (Etteger et al., 2014)

By overlapping these two maps, I could identify the water bodies in high heat-stress residential areas in Utrecht, which form my research area for further analysis:

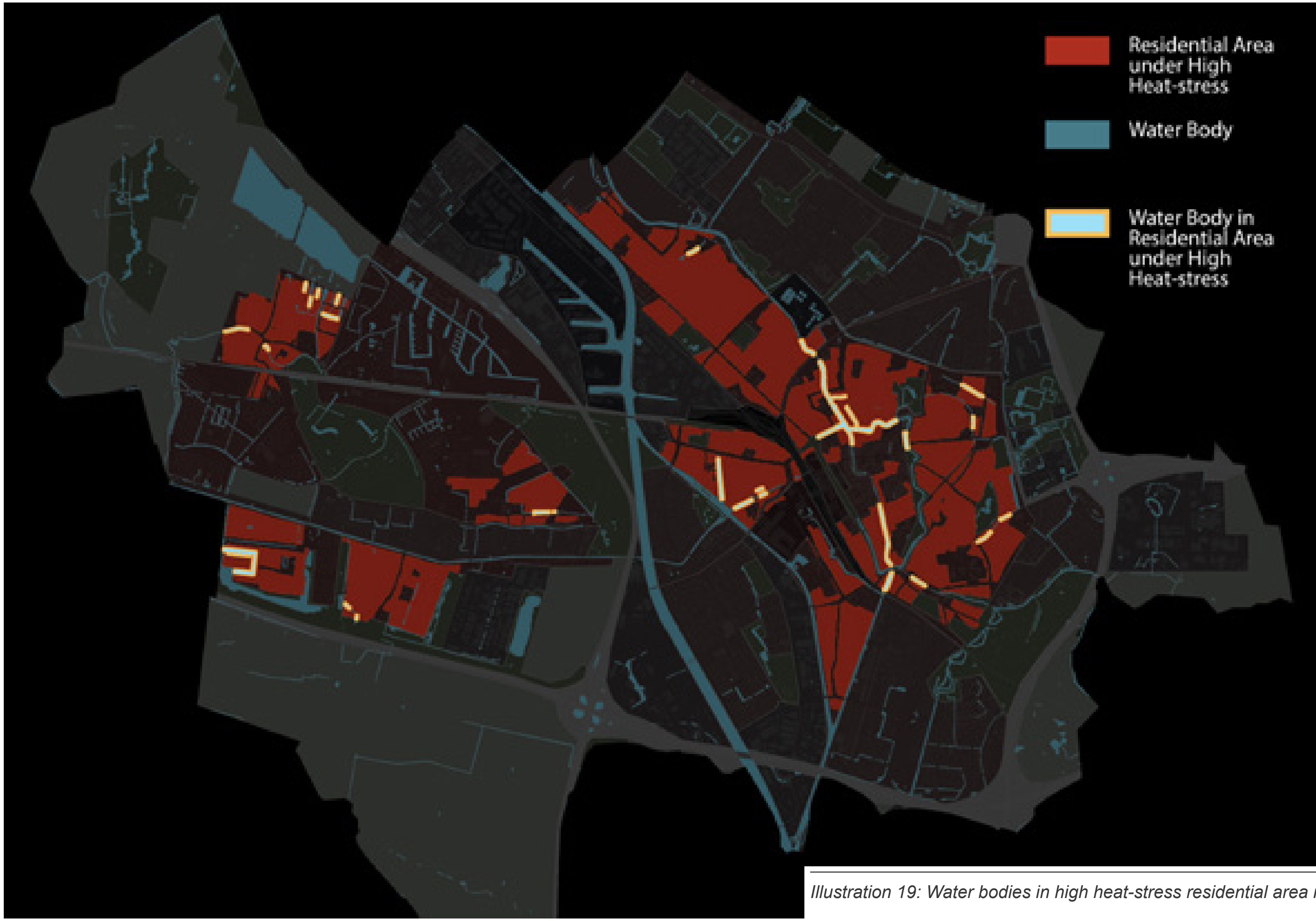


Illustration 19: Water bodies in high heat-stress residential area map of Utrecht

4.2 Types of Test-beds

After taking a close look at the water bodies, it occurred that all the water bodies are canals. But there are all kinds of canals in terms of their profiles. The arrangements of canal, houses, gardens, trees, roads vary.

After a thorough study through the Google street views on Google map, the patterns of the profiles are concluded into 11 canal types, which are regardless of the proportions of components, but concerned about the sequence of them:

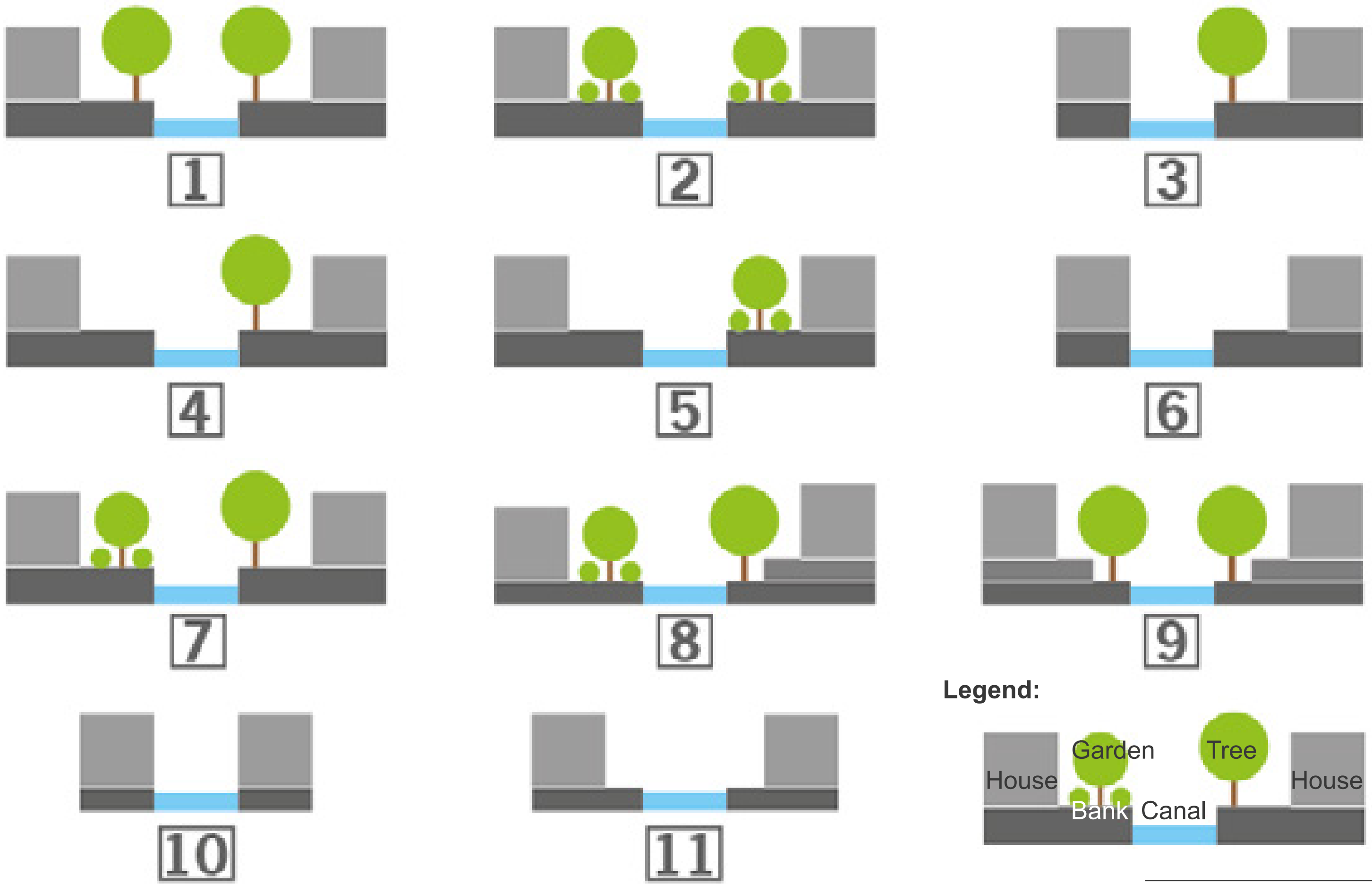


Illustration 20: Canal types in the research area

The 11 canal types are located on the map as:

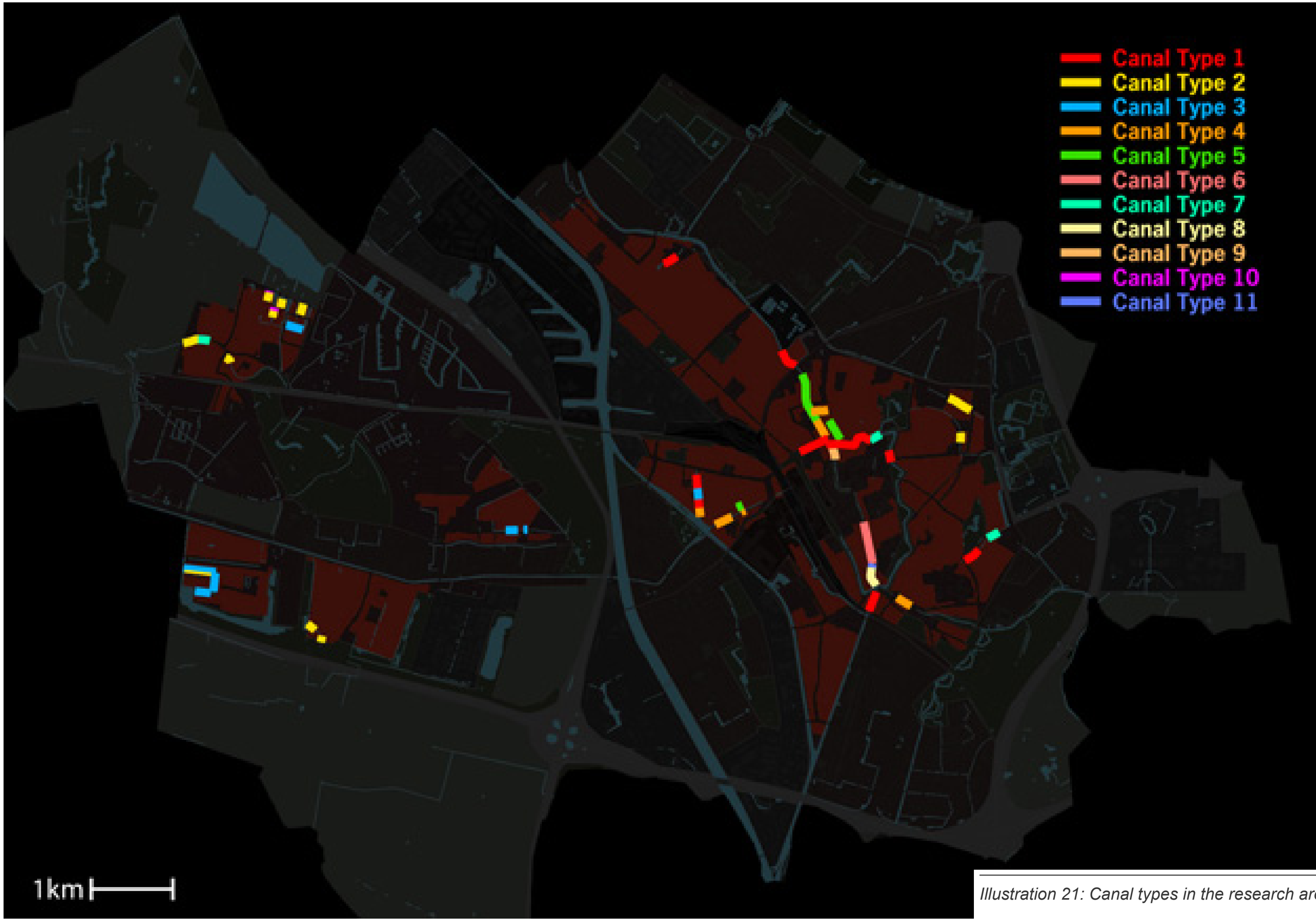


Illustration 21: Canal types in the research area on map

4.3 Orientations of Test-beds

Not all of the canal types are representative. As shown in Illustration 21, some types are very short. So I decided to measure all the lengths of the relevant canals stretches on map, and calculate the accumulated length of each type of canal, the result is as such:

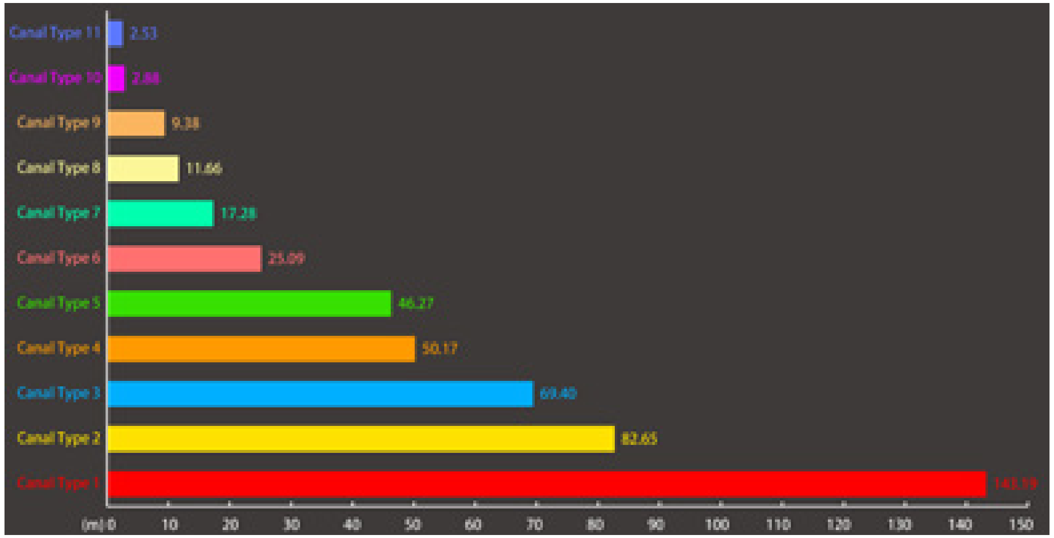


Illustration 22: The lengths of 11 canal type stretches

From the chart, there are three outstanding canal types in terms of the accumulated length of stretch, they are canal types 1, 2 and 3 out of the 11 types. These three canal types are with typical profile arrangements (Illustration 20). For their distribution on map see Appendix I. The canal type 1 is with two rows of street trees neighboring the canal, both rows of trees are on a street with traffic next to a row of houses. Canal type 2 is with two rows of private back gardens connected to the canal, with two rows of houses connected to the gardens. Canal type 3 is, on one side of the canal directly facing a row of houses, on the other side however the house and canal are separated by a street with a row of trees neighboring the canal.

The orientation of canals influence the shadow and local wind behavior, so it is also necessary to determine the dominant orientations of test-beds, to finalize the identification. The orientations are simplified into 4 main directions: N-S, E-W, NE-SW, NW-SE (Illustration 23).

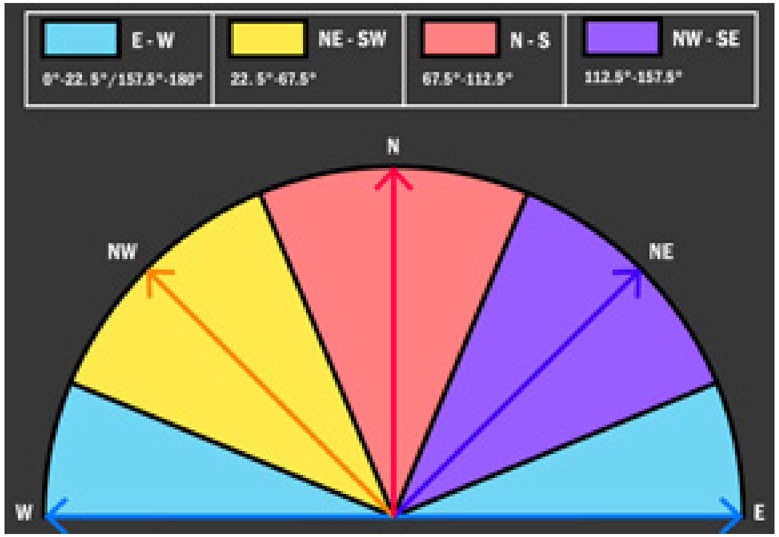


Illustration 23: Defined 4 orientations of canals in this thesis

4.4 Final Identified Test-beds

The result of categorizing the canals into the four orientations shown on map can be found in Appendix II. Again, by accumulating the lengths of the stretches of each orientations, I choose the longest two of them. The lengths of each stretch of canal orientation are:

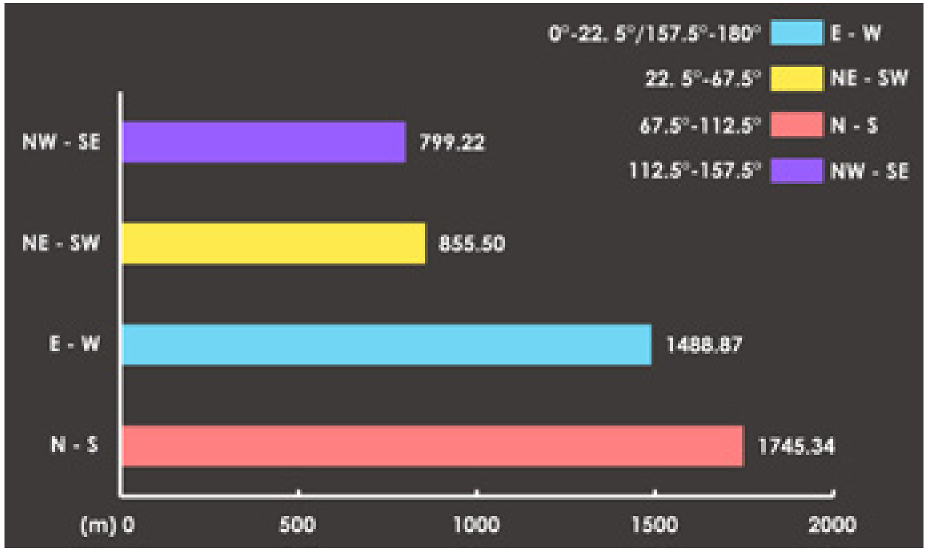


Illustration 24: The accumulated length of each orientation of the 3 types of canals

It can be seen that the N-S and E-W orientations are the dominant ones. With this final restraint, the test-bed identification can be finalized.

With the two dominant orientations, the first two symmetric canal types are becoming Canal Type 1 N-S, Canal Type 1 E-W; Canal Type 2 N-S, Canal Type 2 E-W. The third canal type is not symmetric, results in: Canal Type 3-1 N-S, Canal Type 3-1 E-W; Canal Type 3-2 N-S, Canal Type 3-2 E-W. For the sake of convenience, they are named as: Canal 1-1, 1-2; Canal 2-1, 2-2; Canal 3-1-1, 3-1-2; Canal 3-2-1, 3-2-2, accordingly. They are shown as such:

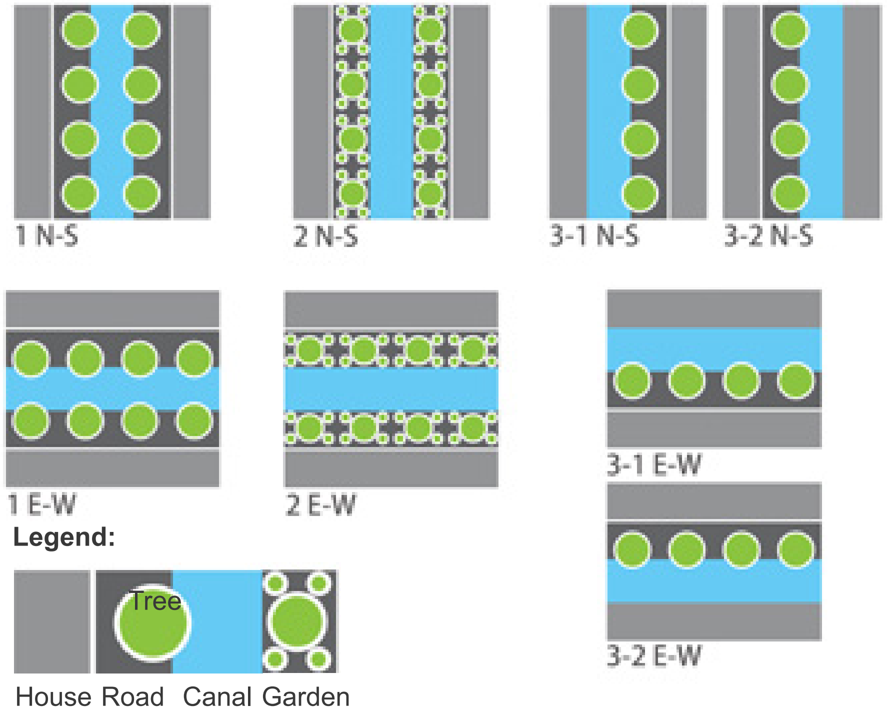


Illustration 25: Profiles of final identified test-beds

4.5 Concretely Fix-scaled Test-beds

To refine the spatial information of the test-beds, detailed shadow and wind analysis have to be executed, for they are fundamental to designing for heat-stress mitigation. For that purpose, the detailed scale of the test-beds have to be determined, because shadow and wind behaviors differ according to different ratios of components. For instance, trees can cast sufficient shadows onto the canals, if the canal is narrow enough, or the trees are large enough; the ventilation can be sufficient, if the width/height (W/H) of the canal canyon is big enough to let the crossing local wind to come into it (Krautheim et al., 2014; Lenzholzer, 2013; Oke, 1987). Measurements of test-beds should be taken to calculate the average scales, which are taken as representative scales of the research areas.

For the measurements in reality are too various, I then took a systematic random sampling method (Kumar, 2011). In the 12 sub-divisions of research areas (see Appendix I), I took numerous sample points of each canal roughly every 100 meters for measuring. The sampling points are not exactly 100 meters from each other for practical reasons such as when the canal already ends when it is not 100 meters yet from the last point, etc. Thus, the sampling points on the map can be illustrated as such:

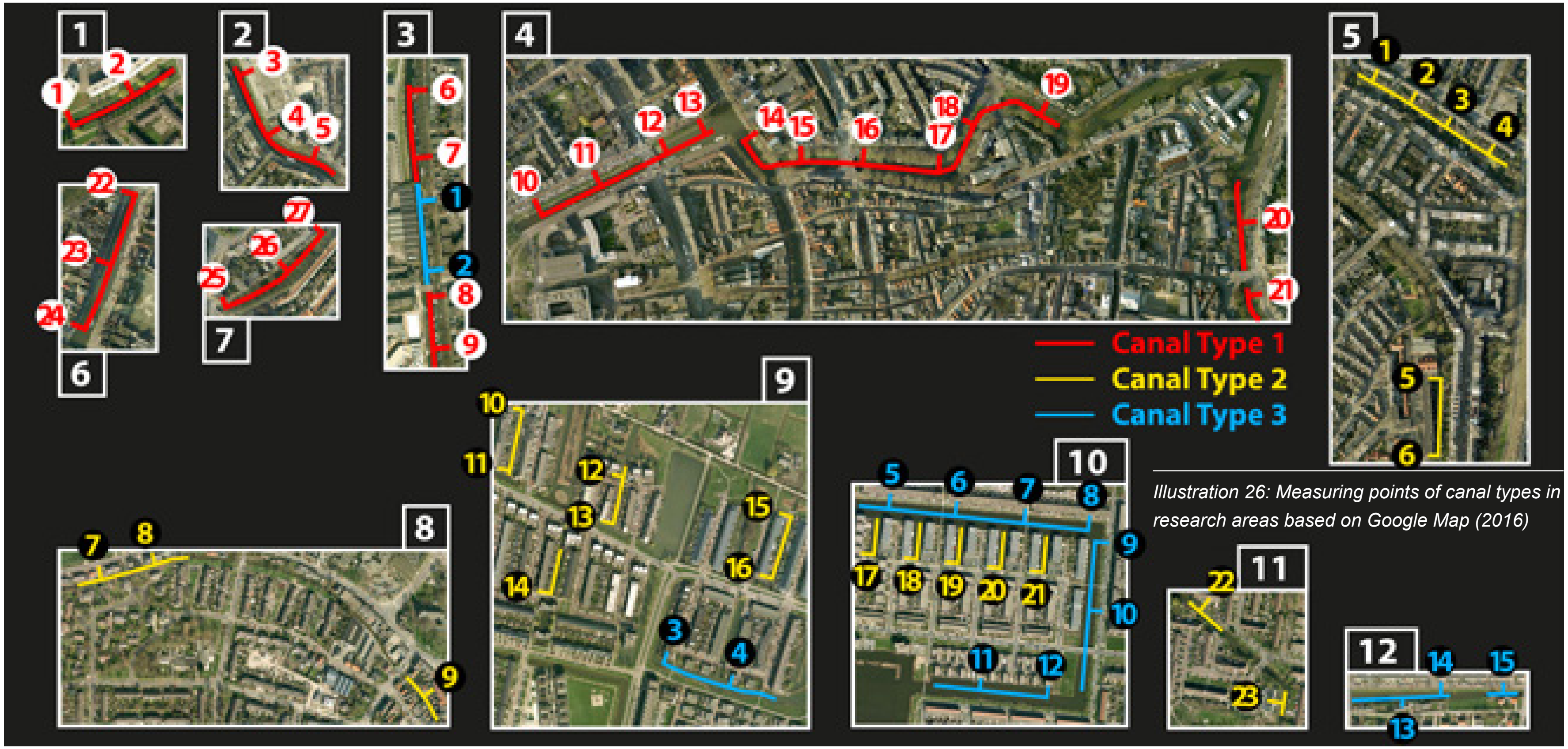
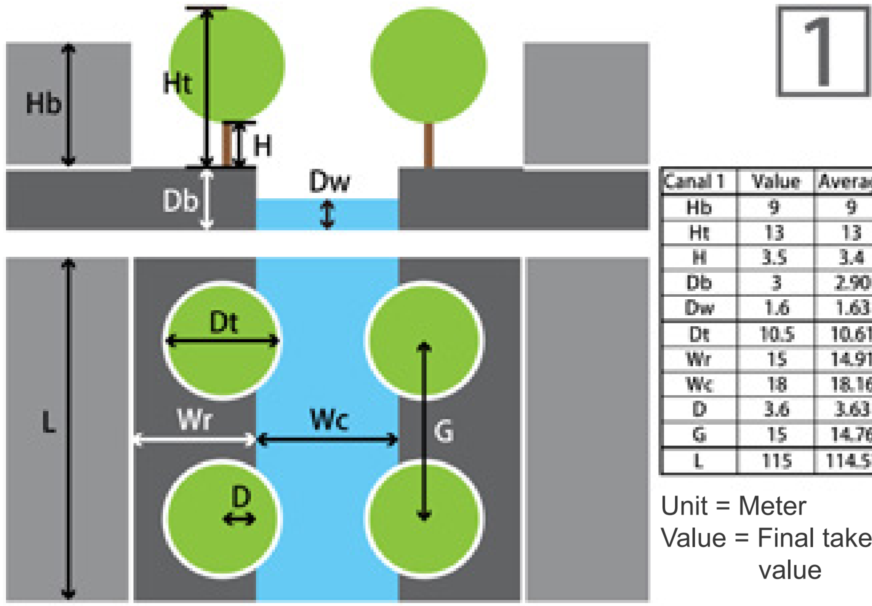


Illustration 26: Measuring points of canal types in research areas based on Google Map (2016)

The depths of canal are measured in field. Usually it is deeper in the middle of the canals than it is near the canal banks, so it is an averaged value. All the measurements are with tolerable measuring errors. Since the point is not to have accurate fixed models, but rather to have more representative models, the tolerance ought to be rather large.

Illustration 27/28: Field work of measuring canal depth

All the sizes and positions of the components in the canal types are measured (see the definitions below to check the values that are measured). The values got from the sample points are averaged first. The final values are the closest value that is convenient for calculations. Measurements for each canal type are as follows:



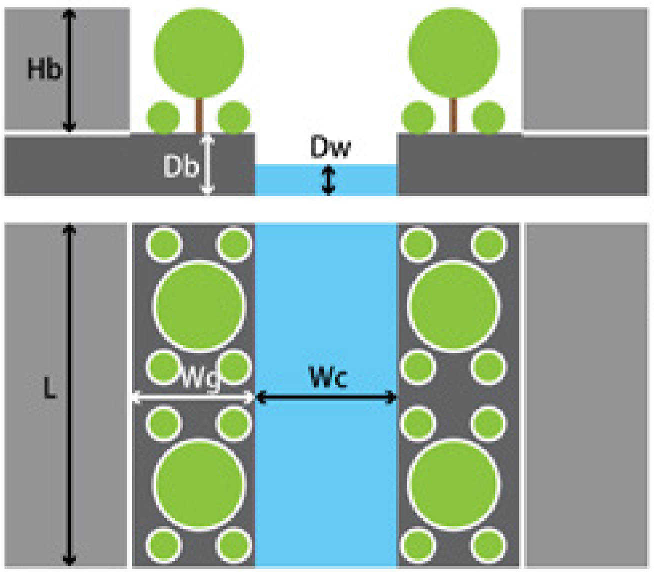
Canal 1	Value	Average
Hb	9	9
Ht	13	13
H	3.5	3.4
Db	3	2.90
Dw	1.6	1.63
Dt	10.5	10.61
Wr	15	14.91
Wc	18	18.16
D	3.6	3.63
G	15	14.76
L	115	114.51

Unit = Meter
Value = Final taken value

Illustration 29: Measurements of Canal Type 1

Definitions:

Hb = Height of house
Ht = Height of tree
H = Height between ground and bottom of tree crown
Db = Height of canal bank
Dw = Depth of canal
Dt = Diameter of tree crown
Wr = Width of road
Wc = Width of canal
D = Horizontal distance from edge of canal bank to tree trunk
G = Horizontal distance of tree gap
L = Length of the canal type stretch

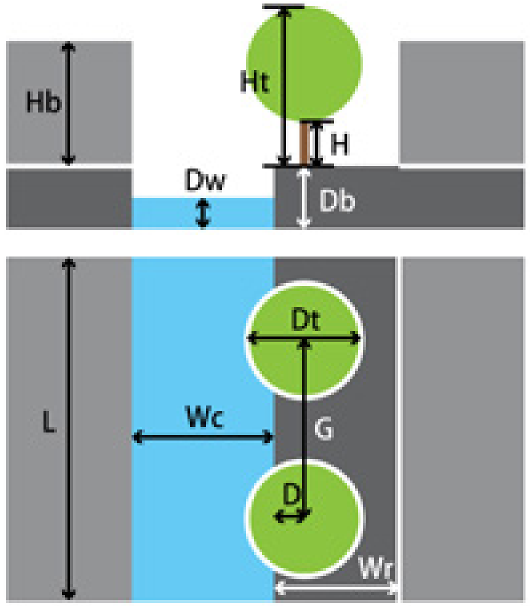


2

Canal 2	Value	Average
Hb	8	8
Db	1.6	1.55
Dw	1.4	1.35
Wg	9	9.14
Wc	9	8.94
L	95	94.52

Unit = Meter
Value = Final taken value

Illustration 30: Measurements of Canal Type 2



3

Canal 3	Value	Average
Hb	7	7
Ht	9	9
H	2	1.8
Db	2	2.03
Dw	1.4	1.37
Dt	5.5	5.60
Wr	16	15.71
Wc	20	19.87
D	3	2.88
G	13	13.25
L	185	185.07

Unit = Meter
Value = Final taken value

Illustration 31: Measurements of Canal Type 3

Definitions:

Hb = Height of house
Db = Height of canal bank
Dw = Depth of canal
Wg = Width of garden
Wc = Width of canal
L = Length of the canal type stretch

Definitions:

Hb = Height of house
Ht = Height of tree
H = Height between ground and bottom of tree crown
Db = Height of canal bank
Dw = Depth of canal
Dt = Diameter of tree crown
Wr = Width of road
Wc = Width of canal
D = Horizontal distance from edge of canal bank to tree trunk
G = Horizontal distance of tree gap
L = Length of the canal type stretch

Based on these further analyses, I was able to build three typical canal types. They are illustrated as following:

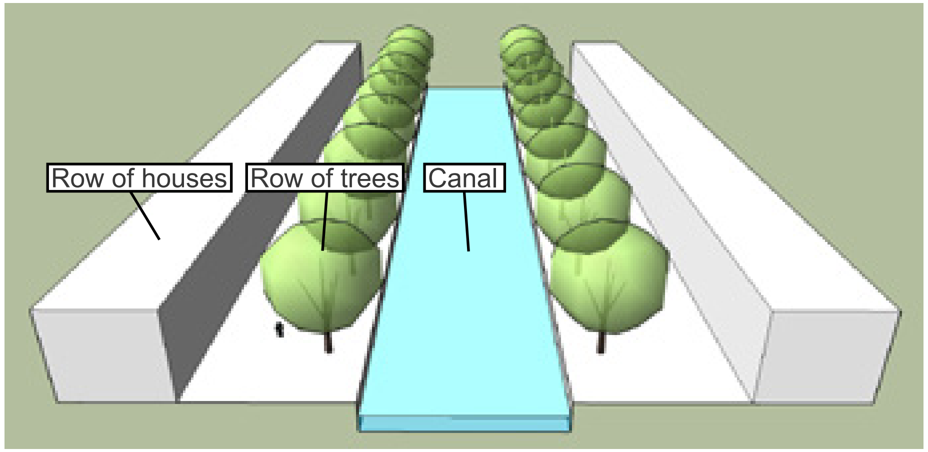


Illustration 32: Model of Canal Type 1

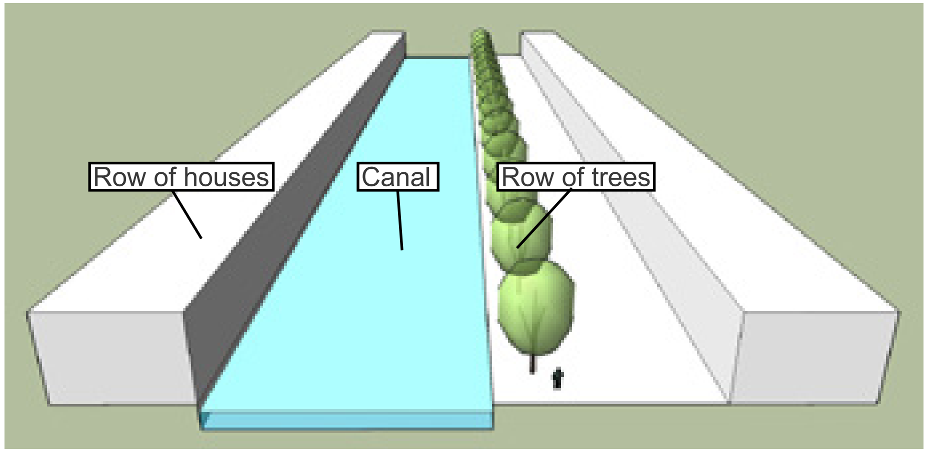


Illustration 34: Model of Canal Type 3

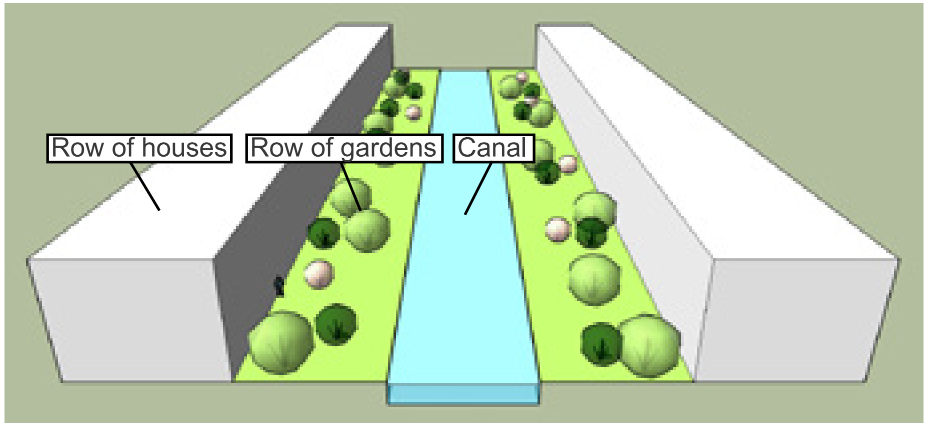
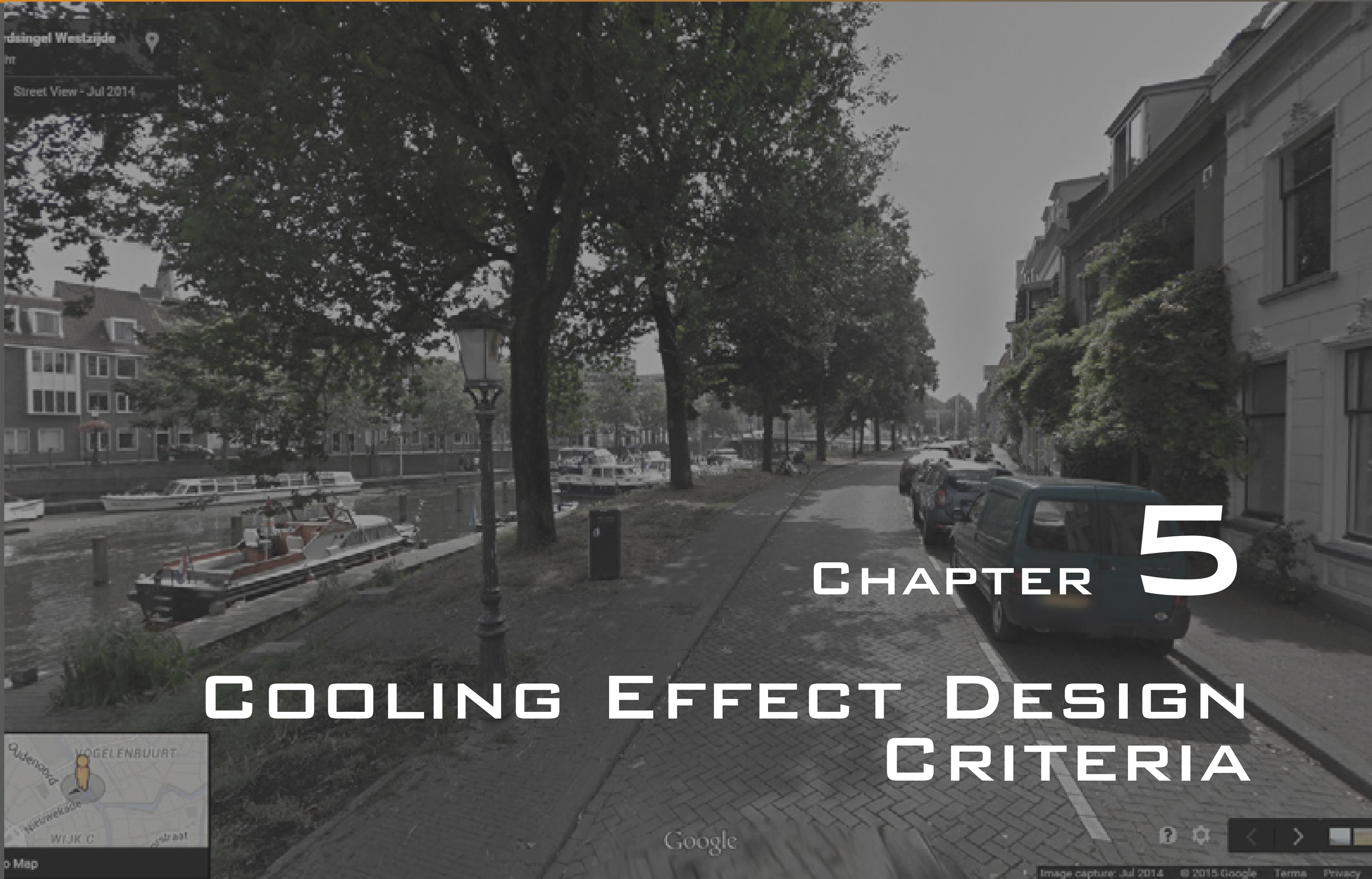


Illustration 33: Model of Canal Type 2

By adjusting the orientations of the canal type models, all the test-beds' models are created.



Chapter 5

Cooling Effect Design Criteria

With the concretely fix-scaled models of test-beds, shadow and wind analyses can be operated. According to the analyses results, the three cooling mechanisms: shading, evapotranspiration, and ventilation, can be embedded. To maximize the synergy, the interventions should encourage at least one mechanism, and not weaken the others much. In this way, the design criteria can be identified.

5.1 Shadow Analysis of Test-beds

By inputting the geographical location of Utrecht, and locating my models there in Sketch Up, I was able to actually simulate the shadow situation of my test-beds. It is however important to decide on which date to simulate the shadow since it is different gradually day to day as show below:

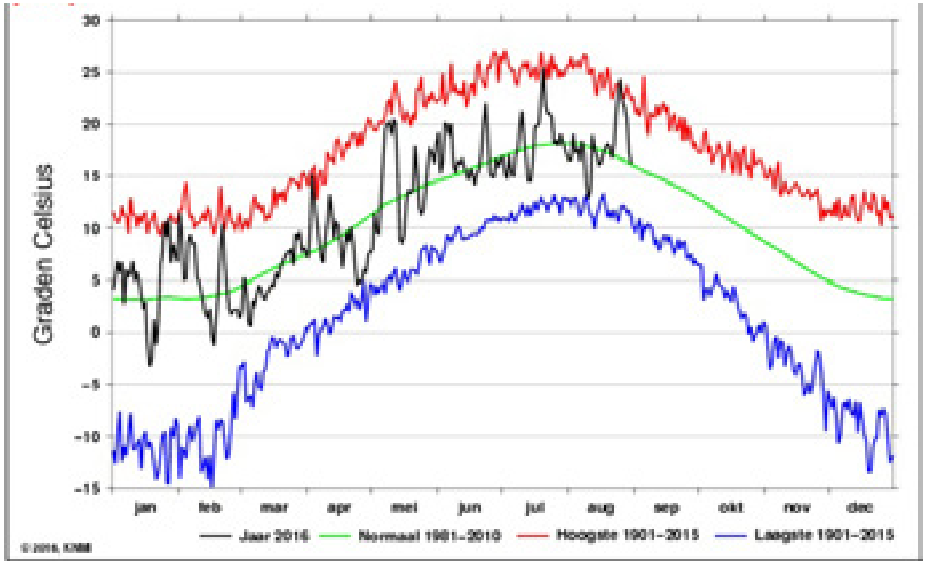


Illustration 35: Yearly Air temperature of Utrecht (KNMI, 2016)

In Illustration 35, it can be observed that the air temperature peak is around the end of July and the begging of August. Based on that I chose 1st of August as the representing date to do the shadow analysis. The next step to determine is the hours of the day to simulate the shadows. As solar radiation is not always the same during the day (Illustration 36).

I chose 10, 11, 12, 13, 14, 15, 16 o'clock points in time for representing maximum solar radiation, between 10-16 hours. I simulated shadows in Sketch Up, and overlaid them. For results see following pages.

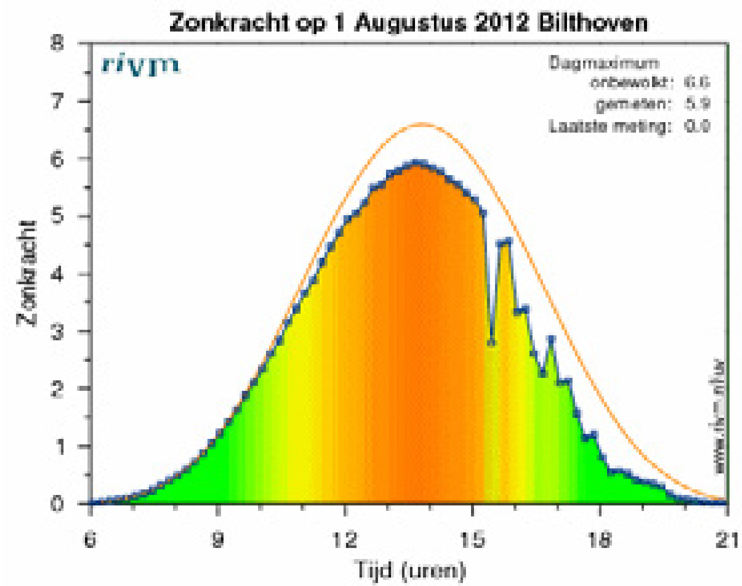


Illustration 36: Solar radiation strength during the day on 1 August (KNMI, 2016)

The results of the simulations are demonstrated as follows:

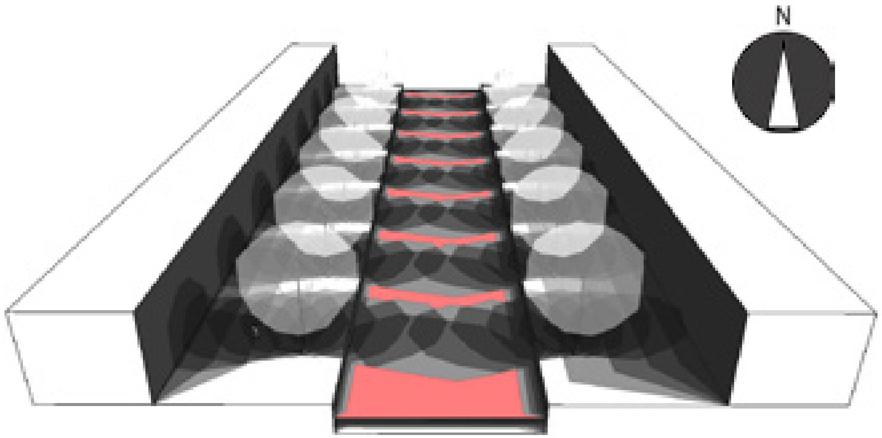


Illustration 37: Shadow analysis of Canal 1-1

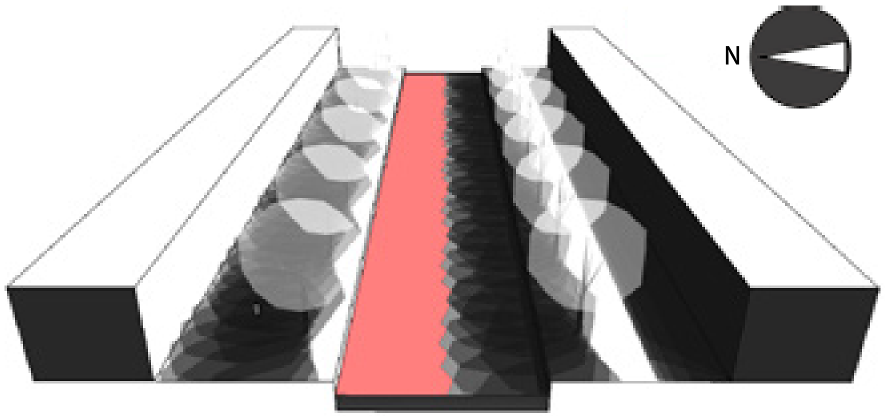


Illustration 38: Shadow analysis of Canal 1-2

Area of canal fully exposed in sun during the day.

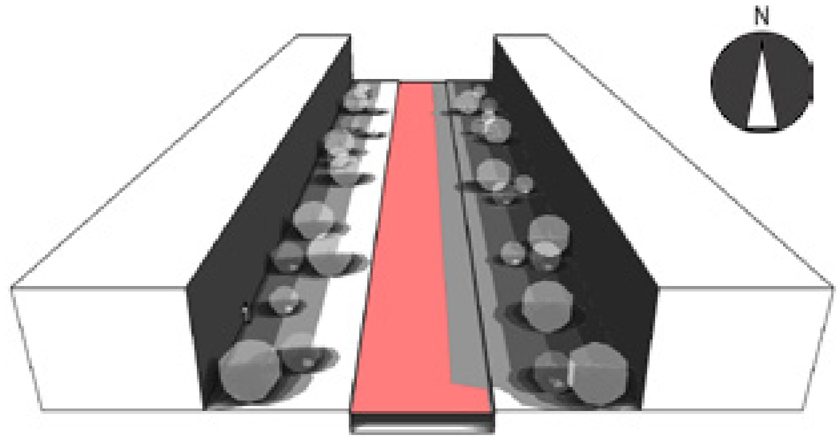


Illustration 39: Shadow analysis of Canal 2-1

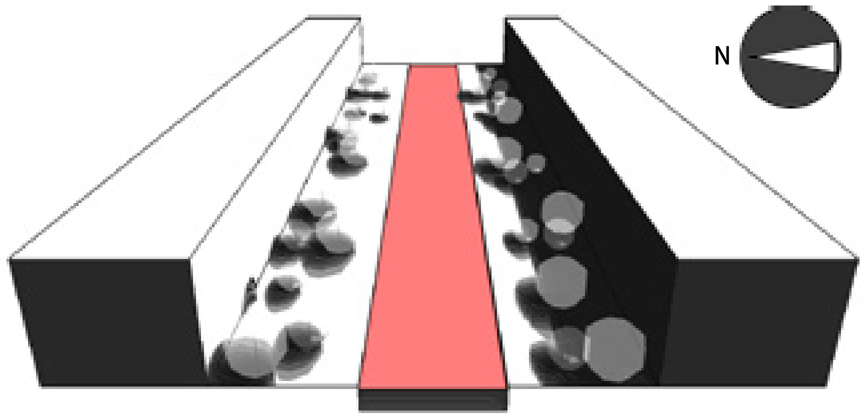


Illustration 40: Shadow analysis of Canal 2-2

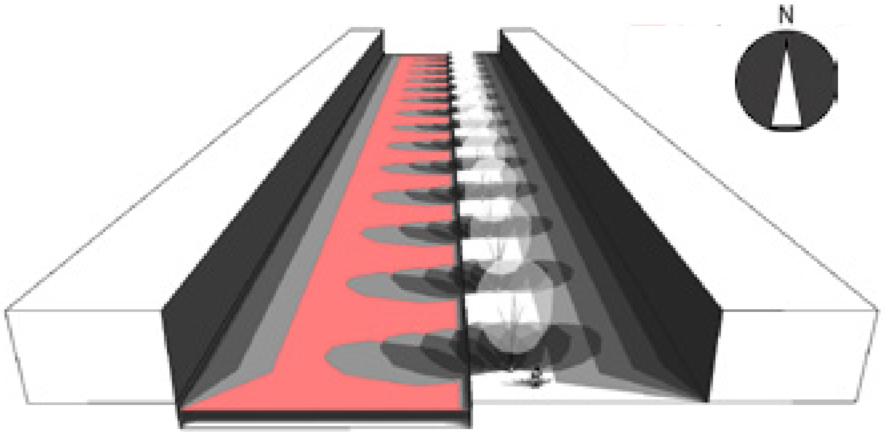


Illustration 41: Shadow analysis of Canal 3-1-1

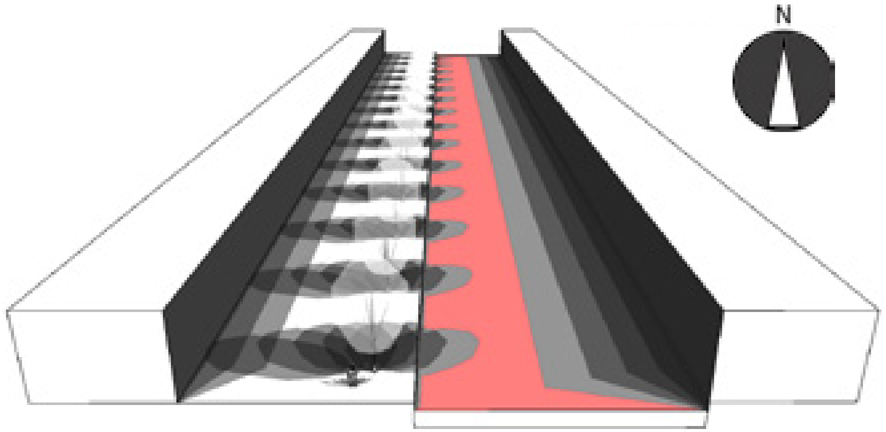
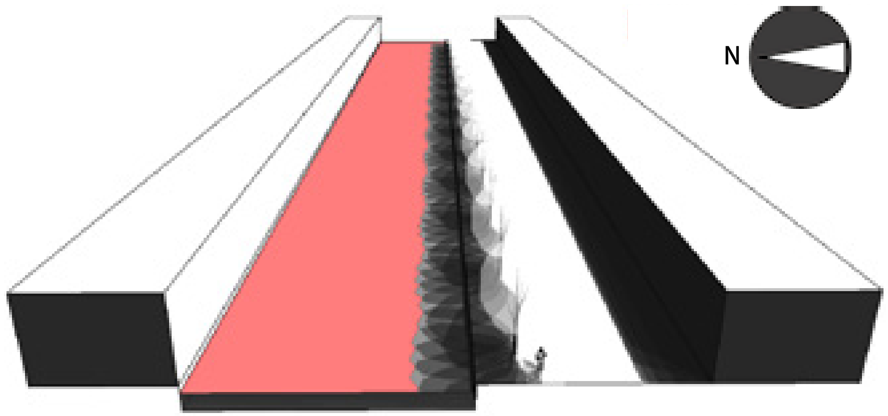


Illustration 43: Shadow analysis of Canal 3-2-1



Area of canal fully exposed in sun during the day.

Illustration 42: Shadow analysis of Canal 3-1-2

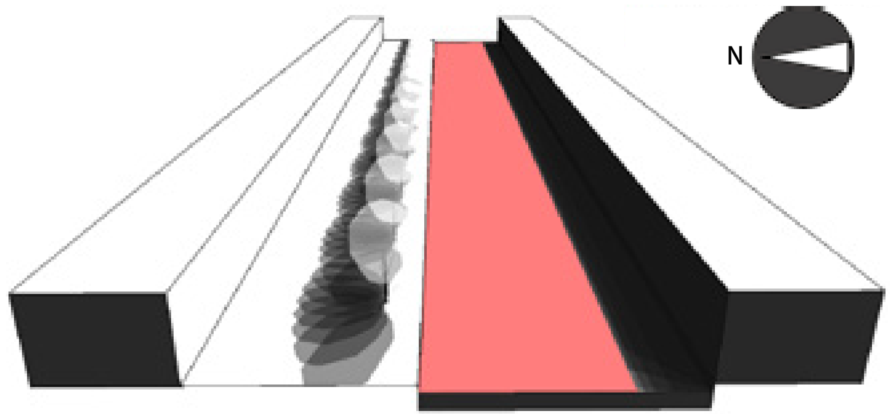


Illustration 44: Shadow analysis of Canal 3-2-2

5.2 Wind Analysis of Utrecht

From the results we can see that Canal 1-1 is the least exposed in radiation, only some gaps of the trees' shadows on the canal are completely exposed to sun. And because the trees in this type of canal are large, the shadow gaps are therefore quite small. Canal 1-2 is much more exposed, almost more than half of the canal is completely exposed in sun throughout the day. Canal 2-1 and 2-2 are even more exposed, almost the whole canals are completely exposed in sun during the hot hours. Canal 2-1 is a little less exposed than 2-2 for it is a little covered by the trees' shadows in relatively not so hot hours, but the effect is little. Canal 3-1-1 is more than half-covered by the shadows of the houses and the trees' shadows. 3-1-2 is however much more exposed, roughly 4/5 of the canal is completely exposed to sun. Canal 3-2-1 is with similar condition with 3-1-1, while in 3-2-2's condition, the about 3/4 of the canal is completely exposed to sun.

To conclude, different canal types display different conditions of shadows. In terms of shadow patterns, 3-1-1 and 3-2-1 are similar to 1-1, because they all display gaps of shadows, and less than half of the canal is completely exposed. All the rest however, display a linear pattern of exposed area, and more than half of the canal is completely exposed.

In order to analyze the wind behaviors in test-beds, I used the information of the KNMI, from the station closest to Utrecht, De Bilt. With the information for "Normal" and "Summer Days", I made the wind roses of Utrecht. According to the definition given by KNMI (2016), the "Summer Days" are referring to the days with the max. air temperature above 25 Celsius. The wind roses are as such:

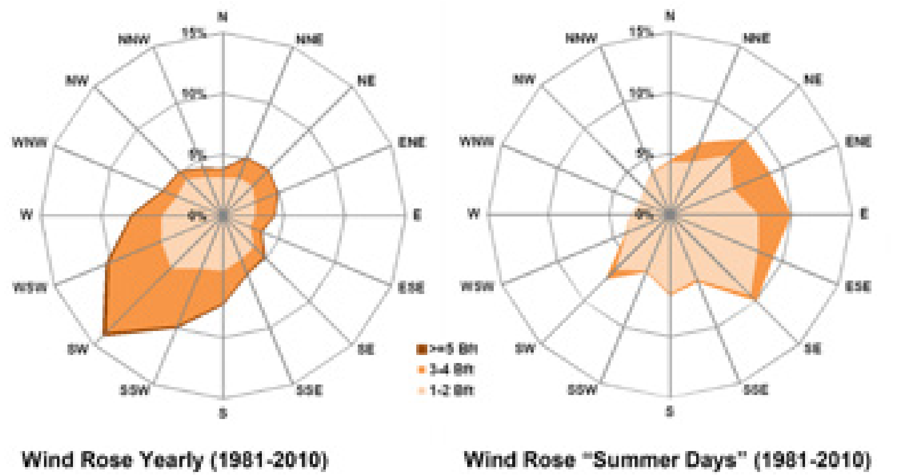


Illustration 45: Wind roses of Utrecht based on KNMI (2016)

From the wind roses we can see that the main wind direction is south-west, and the wind speed is quite. On Summer Days it is mainly from the east, and the wind speed is rather low. According to this result, in this thesis, the east direction wind with low speed is chosen to represent the main wind condition in hot periods of Utrecht.

5.3 Wind Analysis of Test-beds

The patterns of wind behaviors were analyzed according to the literature (Krautheim et al., 2014; Oke, 1987):

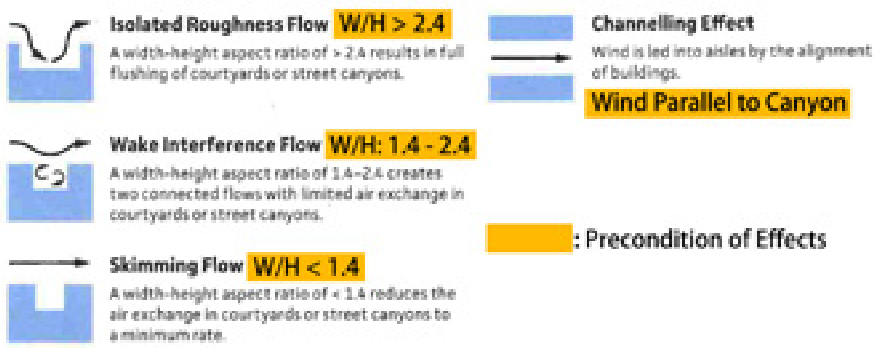


Illustration 46: Wind behaviors relevant (Krautheim et al., 2014)

The roughness of the surface that wind is crossing on is taken into consideration in the analysis In the test-beds, the trees' roughness is larger than the houses', so when the wind meets trees, it slows down more, the corresponding behavior pattern is also weakened (Oke, 1987). According to these patterns, the wind analysis of each test-bed is done as:

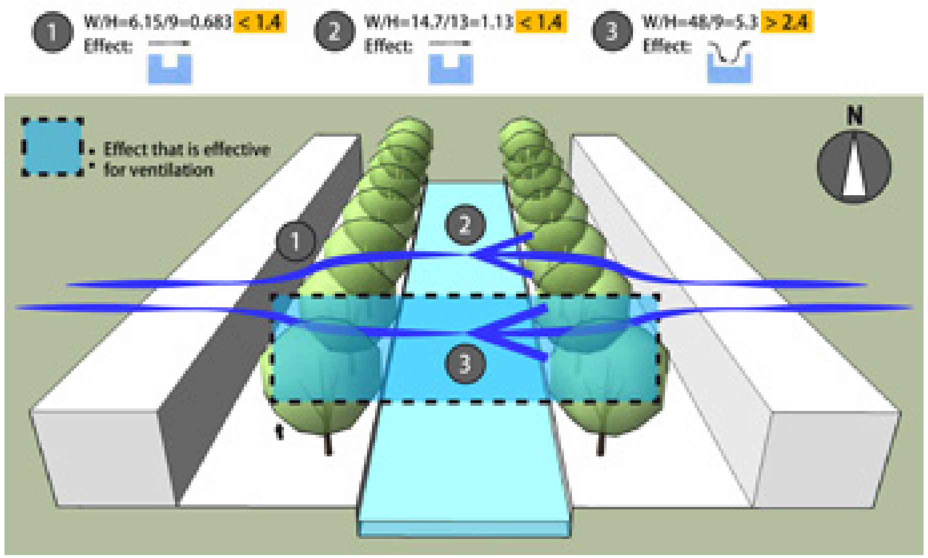


Illustration 47: Wind analysis of Canal 1-1

Wake Interference Flow is an effect that is weaker than Isolated Roughness Flow. Because the wind comes less down into the canyon, and the strength of turbulence caused in canyon is so weak due to the weak Summer Day wind that it can be ignored.

When the wind meets the trees, it skims the gap between trees and houses, then climbs up above the trees, skims the gap between the two rows of trees, and again go down skims the last gap. When the wind meets the gaps of the tree rows, it comes down to the canyon a bit, but the effect is weakened by the roughness of trees.

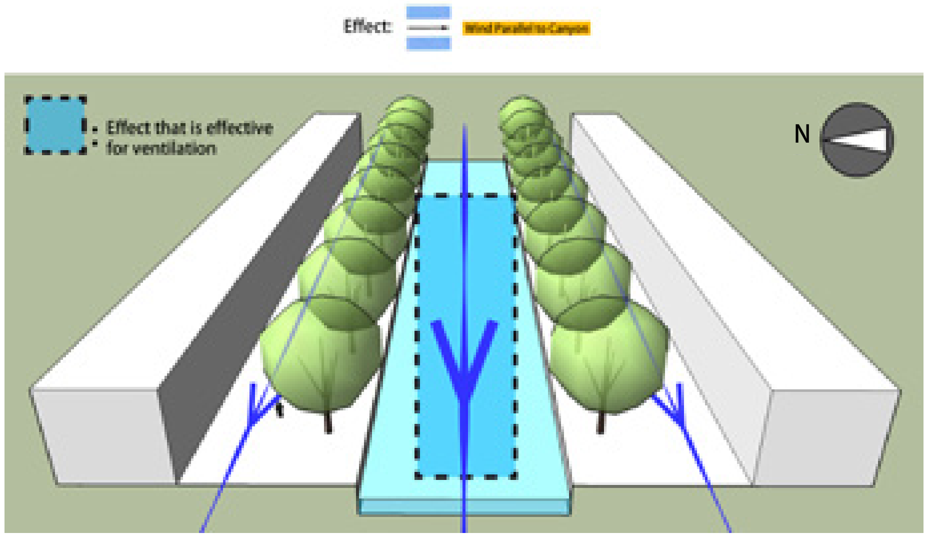


Illustration 48: Wind analysis of Canal 1-2

The wind is simply channeling if it is parallel to the canal, the other analyses are similar to the first two, here I don't unnecessarily describe every each of them.

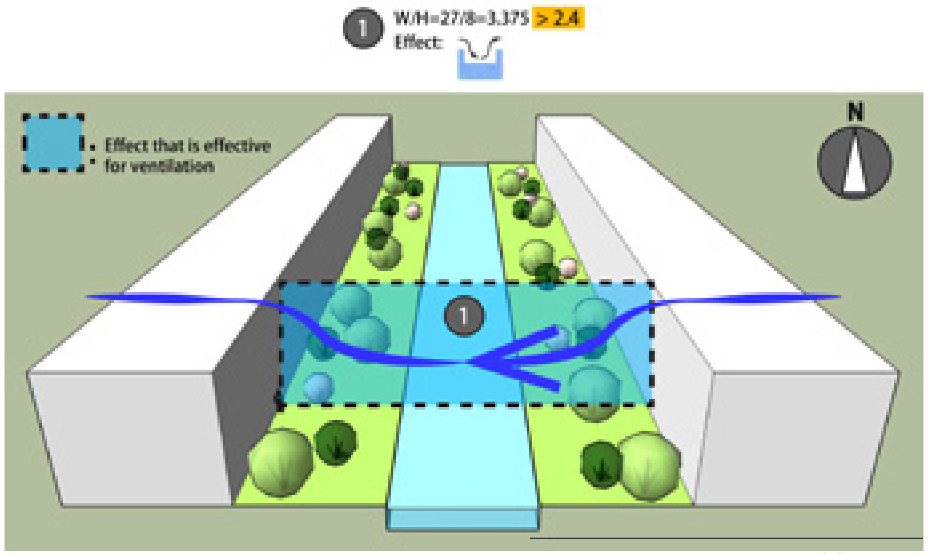


Illustration 49: Wind analysis of Canal 2-1

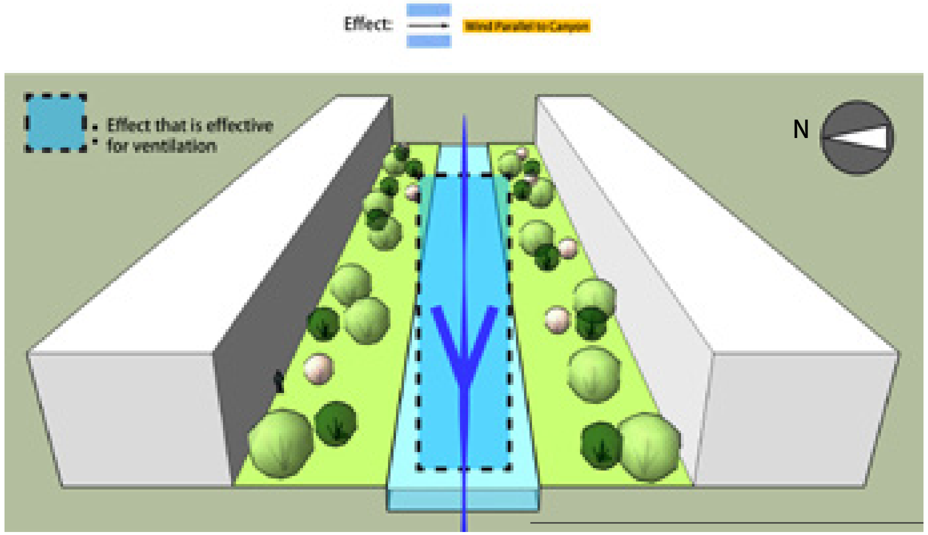


Illustration 50: Wind analysis of Canal 2-2

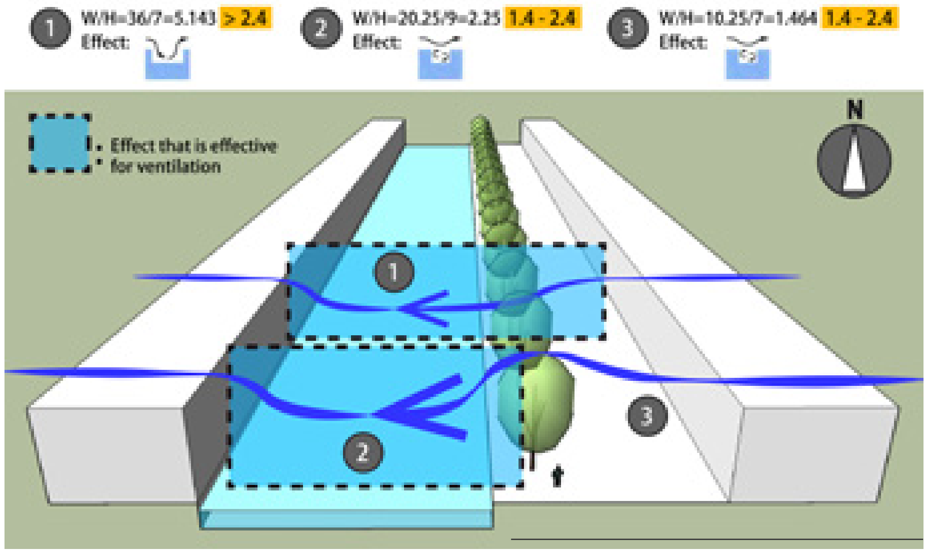


Illustration 51: Wind analysis of Canal 3-1-1

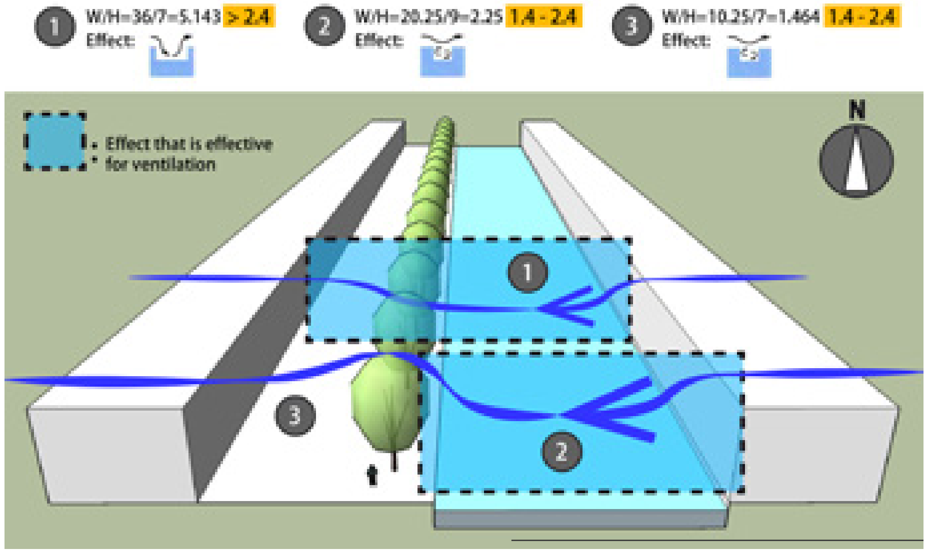


Illustration 53: Wind analysis of Canal 3-2-1

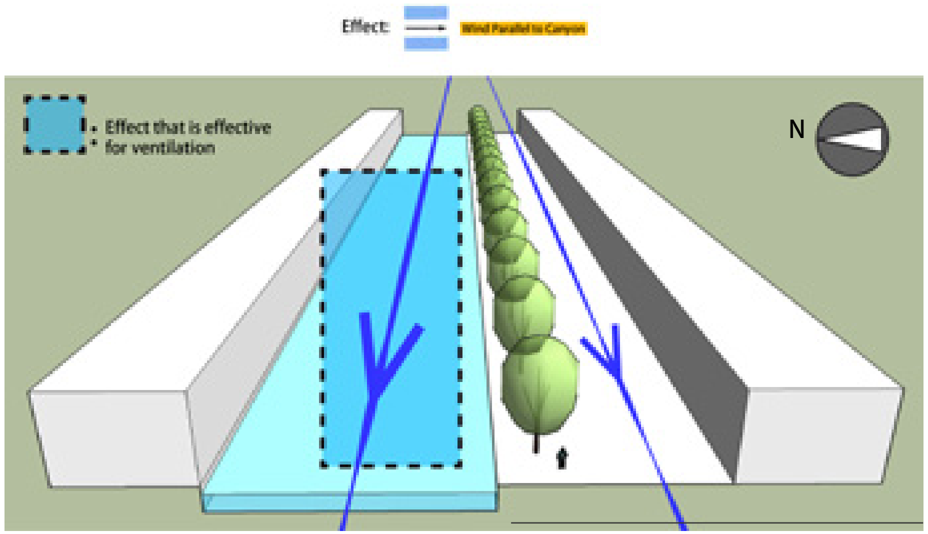


Illustration 52: Wind analysis of Canal 3-1-2

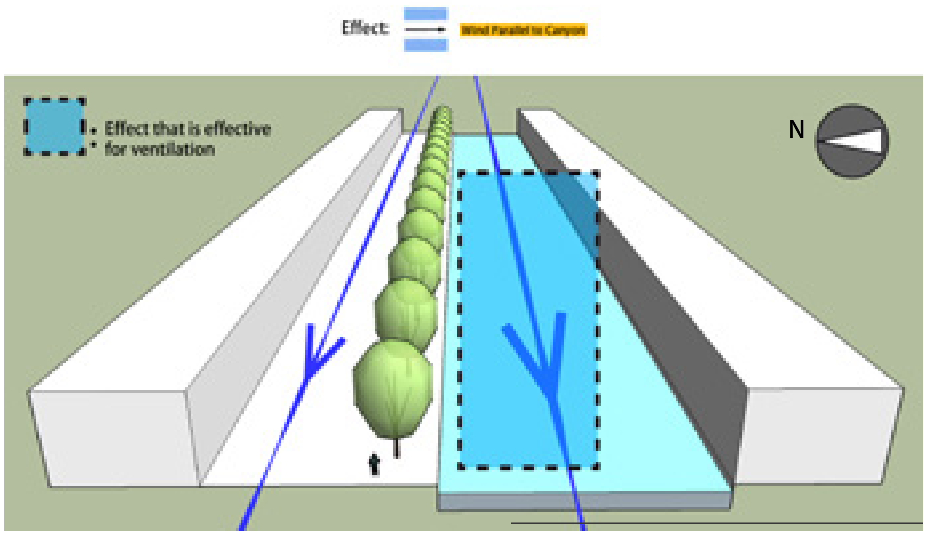


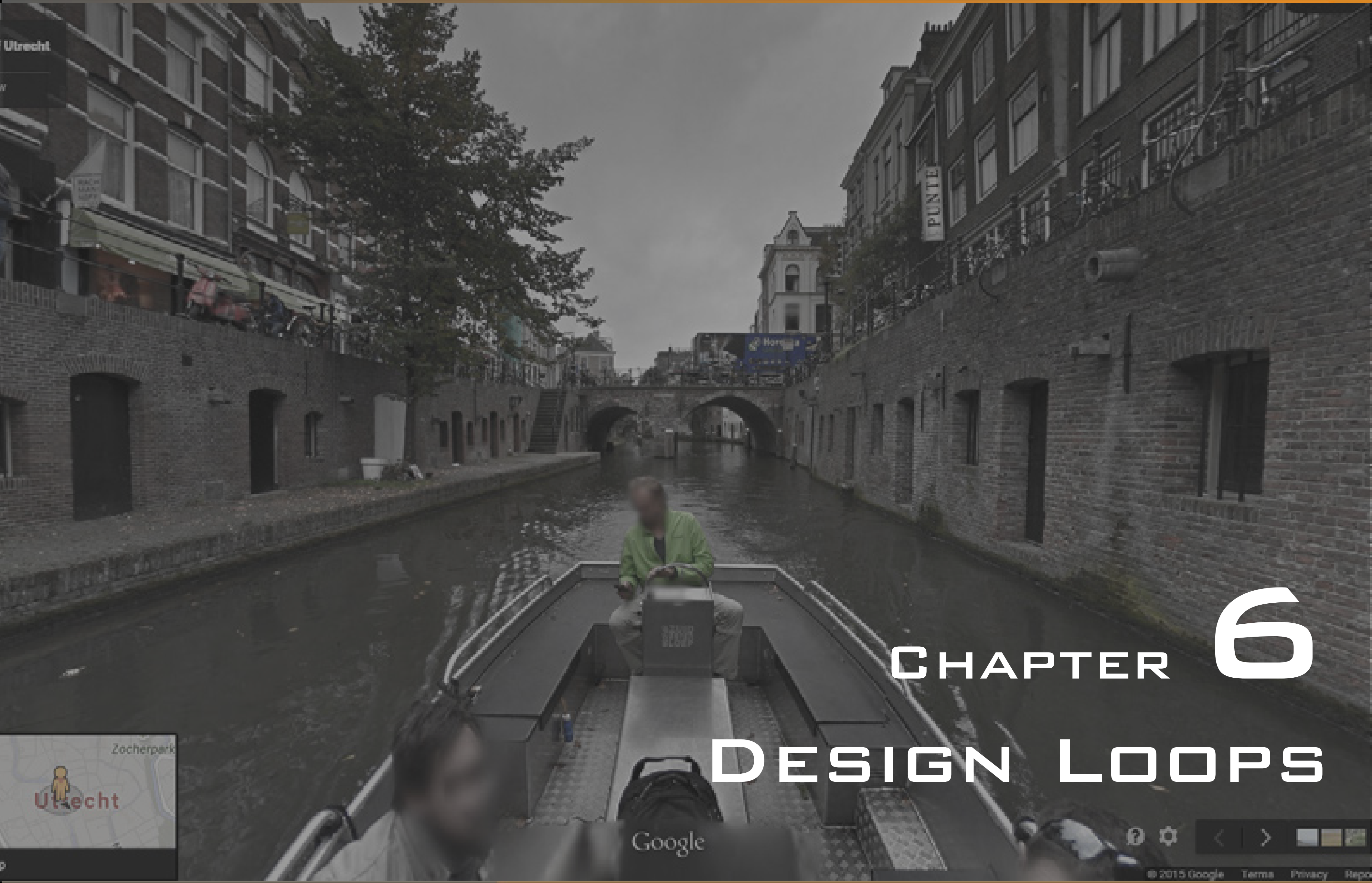
Illustration 54: Wind analysis of Canal 3-2-1

5.4 Cooling Effect Design Criteria

For shading interventions, the red areas in shadow analysis results are recommended to be shaded. Using green for shading has the advantage of transpiring at the same time shading (Erell et al., 2011; Kleerekoper et al., 2012). As sun radiation is the main heat input of the test-beds (Lenzholzer, 2013), shading interventions has priority over other interventions.

For evapotranspiration interventions, to maximize the effect, they are recommended to be placed in the red areas in the shadow analysis results, to received the most radiation. Evaporation can be largely encouraged by spraying water (Nishimura et al., 1998). Transpiration can be encouraged by plating more plants, and the more the water source, the more the transpiration (Erell et al., 2011; Kleerekoper et al., 2012).

For ventilation interventions, as canal water keeps evaporating, water vapor concentrates above canal. It is important for the ventilating wind to go through there. It is also important to integrate the ventilations with the effective wind behaviors in the test-beds from the wind analysis results, so that water vapor and cooled air can be carried away from the test-beds into the regional wind.



Chapter 6
Design Loops

6 Design Loops

The process of the design loops of this thesis is iterative, it goes from basic single designs to integrated designs. By combining and synthesizing, adding more evaluating criteria in later design loops, refinement of the designs was achieved. The whole process can be represented as such:

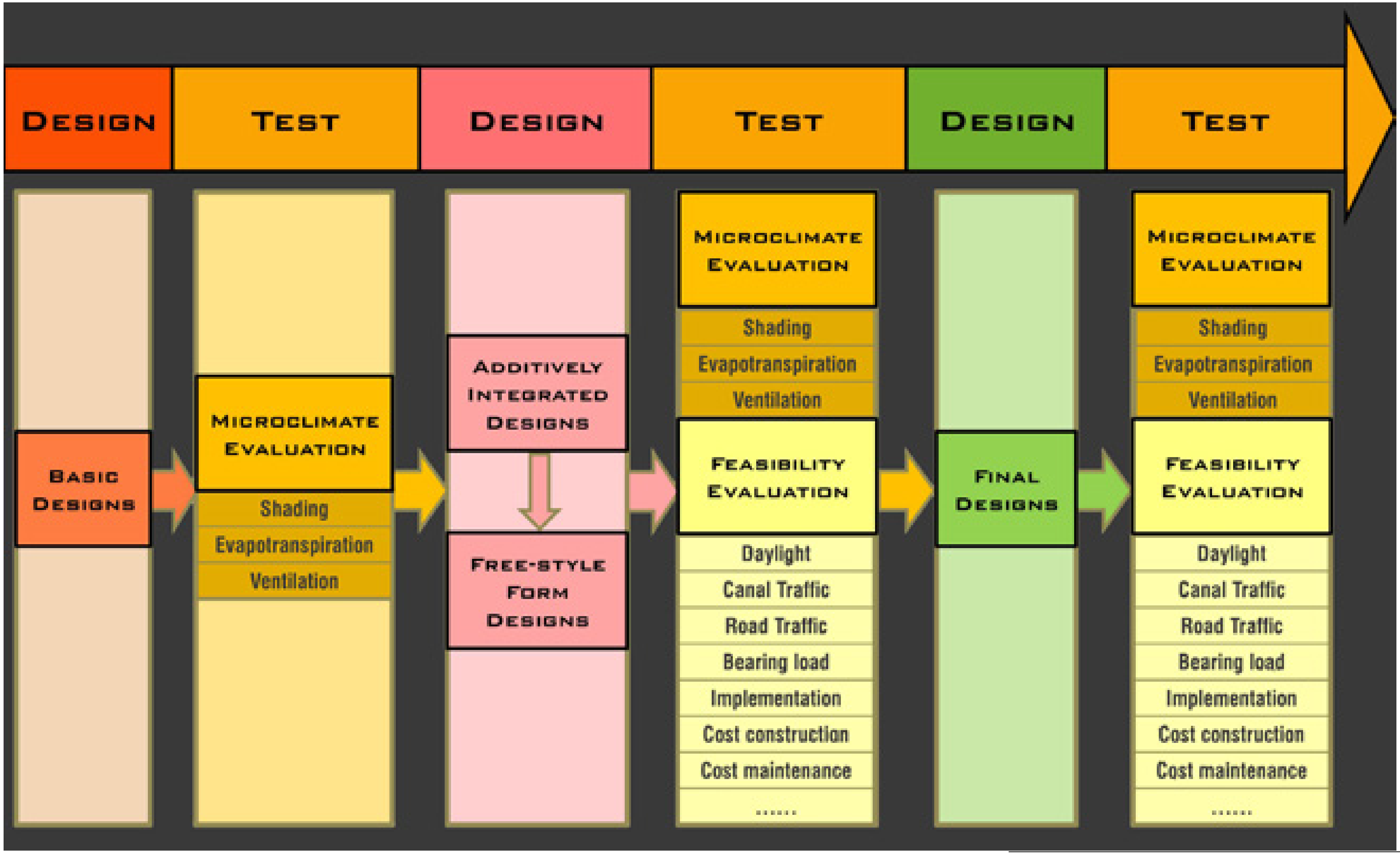


Illustration 55: Flow diagram of the Design Loops process

6.1 Loop 1 Basic Designs

Based on Cooling Effect Design Criteria, I was able to sketch basic single-method designs for heat-stress mitigation of each test-beds. Every design is evaluated on all three cooling mechanisms.

Despite the fact that I made a lot of basic designs for every test-beds, I concluded 5 distinct categories of basic designs for each test-bed: Pergola, Solar Panel, Water Plant, Fountain, and Solar Fan. Two extra categories for both Canal 2-1 and 2-2 because they are without trees and with more space to be designed: Umbrella Tree, Dawn Redwood. The 5 categories of basic designs are applied onto each test-beds, as well as the 2 extras for Canal 2-1 and 2-2.

Basic designs are all evaluated on Shading, Evapotranspiration and Ventilation effects, and reviewed by experts: Sanda Lenzholzer (landscape architecture specialized on urban climate) and Gert-Jan Steeneveld (meteorologist specialized on urban climate). “+” means compared to undesigned situation, the mechanism is enhanced, “-” means weakened, “/” means neutral.

Pergola can shade and transpire with its plants. Solar panels can shade. Water plants can shade and transpire, and according to some researches (Monteith, 1975; Sánchez-Carrillo et al., 2004; W.J. Mitsch, 1986), certain species transpire more than open water surface. Fountains are very effective in encourage evaporation (Nishimura et al., 1998). Solar fans (are solar panels themselves, my invention, theoretically working, technically not tested) can shade and ventilate. Umbrella shaped trees can effectively shade and transpire. Dawn Redwood can transpire very efficiently when planted in water (Chen et al., 2012).

6.1.1 Basic Design & Evaluations for Canal 1-1

Illustration 56: Pergola Design for Canal 1-1

Pergola design for Canal 1-1 is putting pergolas with climbing plants to shade the gaps of the trees’ shadows, and the plants’ transpiration helps to cool, but they are stemming the ventilation of the canal.

Illustration 57: Solar Panel Design for Canal 1-1

This design replaces pergolas by solar panels. Evapotranspiration is barely influenced in this case, but ventilation is still stemmed.

Illustration 58: Water Plant Design for Canal 1-1

Water plants in Design 3 are shading in unshaded gaps and transpiring.

Illustration 59: Fountain Design for Canal 1-1

Fountains in the sun encourage evaporation effectively.

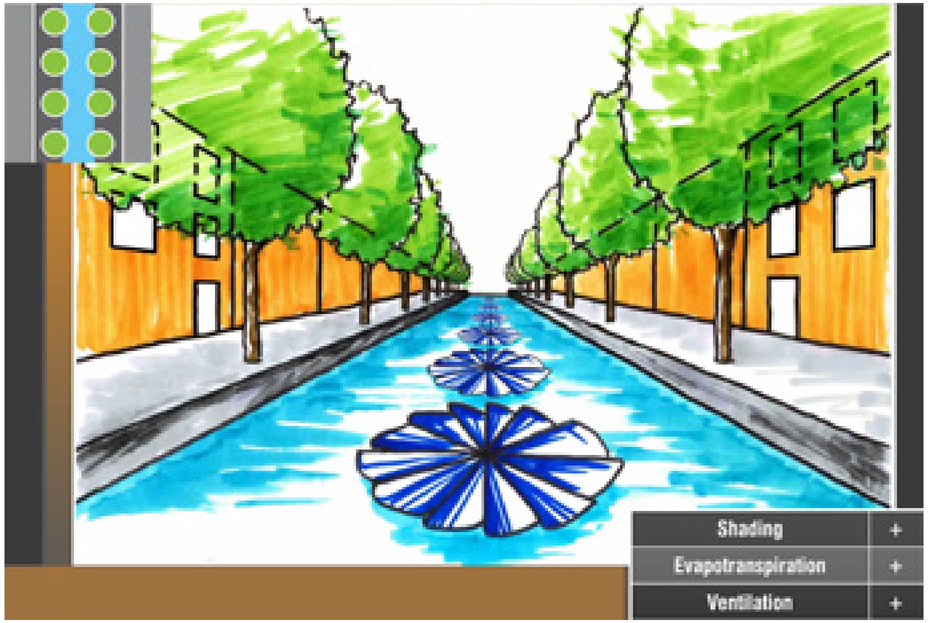


Illustration 60: Solar Fan Design for Canal 1-1

Solar fans placed in the sun shade and ventilate. Because the fans are blowing away water vapor, evaporation is enhanced.

6.1.2 Basic Designs & Evaluations for Canal 1-2

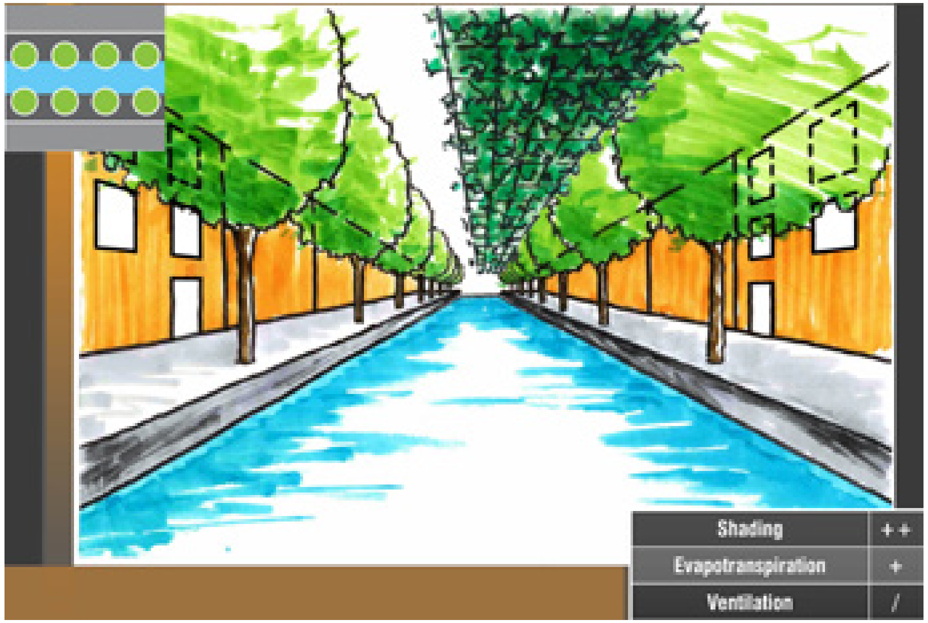


Illustration 61: Pergola Design for Canal 1-2

Illustration 62: Solar Panel Design for Canal 1-2

Pergolas in Canal 1-2 are adapted by locating them on southern side above the canal, so that when the shadow of the pergola on the perpendicular direction of the canal is the longest, which is at noon, will just be wide enough to cover the whole canal.

Solar panels in Canal 1-2 are also adapted by locating them on southern side above the canal, so that when the shadow of the solar panels on the perpendicular direction of the canal is the longest, which is at noon, will just be wide enough to cover the whole canal.

Illustration 63: Water Plant Design for Canal 1-2

Illustration 64: Fountain Design for Canal 1-2

Water plants in Canal 1-2 are planted in the northern side of he canal, so that the water plants shade the part which's completely exposed in sun.

Fountains in Canal 1-2 are moved to the northern side of he canal, so that they are fully exposed in sun and evaporate more.

6.1.3 Extra Basic Designs & Evaluations for Canal 2-1

Canal Type 2 is special because it is the only type without trees. That leaves more space for designing. As trees are very effective in both shading and transpiration, it is logical to provide new trees there.

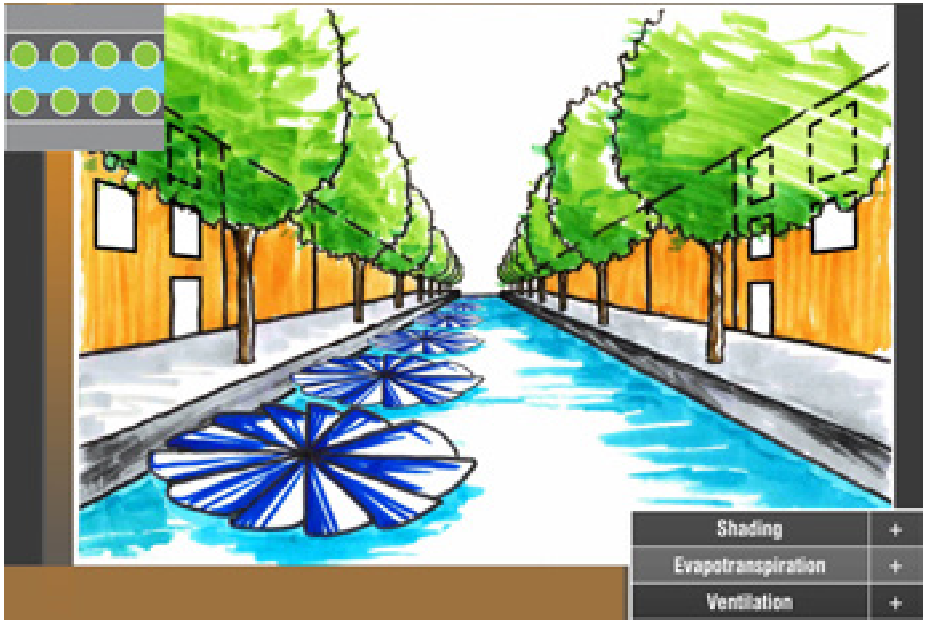


Illustration 65: Solar Fan Design for Canal 1-2

Solar fans in Canal 1-2 are moved to the northern side of the canal simply because the solar fans need sun to power themselves.

Illustration 66: Umbrella Tree Design for Canal 2-1

To maximize the effect of shading, I designed trees which are trimmed in an umbrella like fashion, and still leave gaps for sun intrusion for the houses.

To maximize the transpiration, I chose Dawn Redwood. They can grow in water. Trees transpire more than other forms of vegetation, and they will transpire much more if they are with unlimited water source, especially the species which grow in water (Hüner and Hopkins, 2008; Kleerekoper et al., 2012).

Dawn Redwood (M. glyptostroboides) can perfectly adapt to Dutch climate, because it is very common in temperate climate zones. It is deciduous, so it will not block the sunshine in winters. When planted in soil, Dawn Redwood already transpire almost twice as much as average species (Chen et al., 2012). The charts of Illustration 67 show the comparison of daily amount of transpiration in summer between Dawn Redwood and other commonly seen trees:

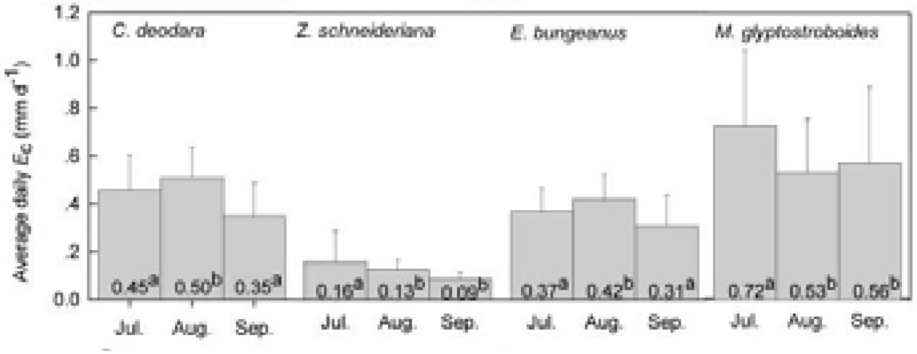


Illustration 67: Comparison of daily amount of transpirations in summer between Dawn Redwood and other commonly seen trees (Chen et al., 2012).

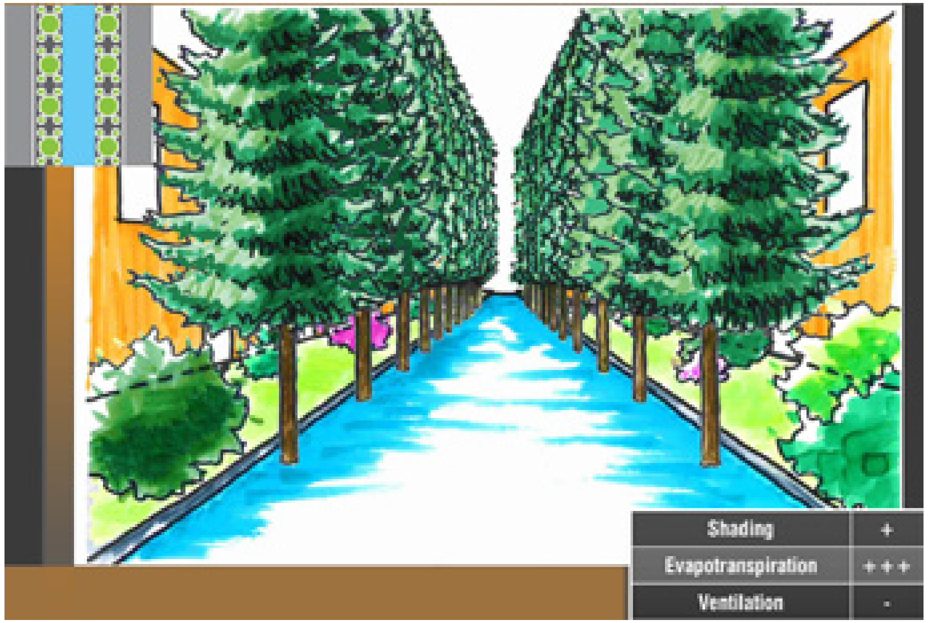


Illustration 68: Dawn Redwood Design for Canal 2-1

The Dawn Redwood trees are rather thin, so they are not as effective in shading. But also because of that, they block less wind, so the ventilation in this situation is better.

6.1.4 Extra Basic Designs & Evaluations for Canal 2-2

The extra two design categories are also adapted to Canal 2-2:

Illustration 69: Umbrella Tree Design for Canal 2-2

The Umbrella Trees are planted only to the southern side of the Canal 2-2, because sun light only comes from one side in this test-bed.

Illustration 70: Dawn Redwood Design for Canal 2-2

The Dawn Redwoods are planted only to the southern side of the Canal 2-2, because sun light only comes from one side in this test-bed.

6.1.5 Other Basic Designs & Evaluations (Details in Appendix III)

The other basics designs and their evaluations are not detailedly described one by one here because: in total 44 basic designs are too many to be in the main body; the other basic designs are similarly adapted according to the Cooling Effect Design Criteria like the aforementioned ones. The following are the thumbnails of all the analyses and basic designs (excl. extra categories):

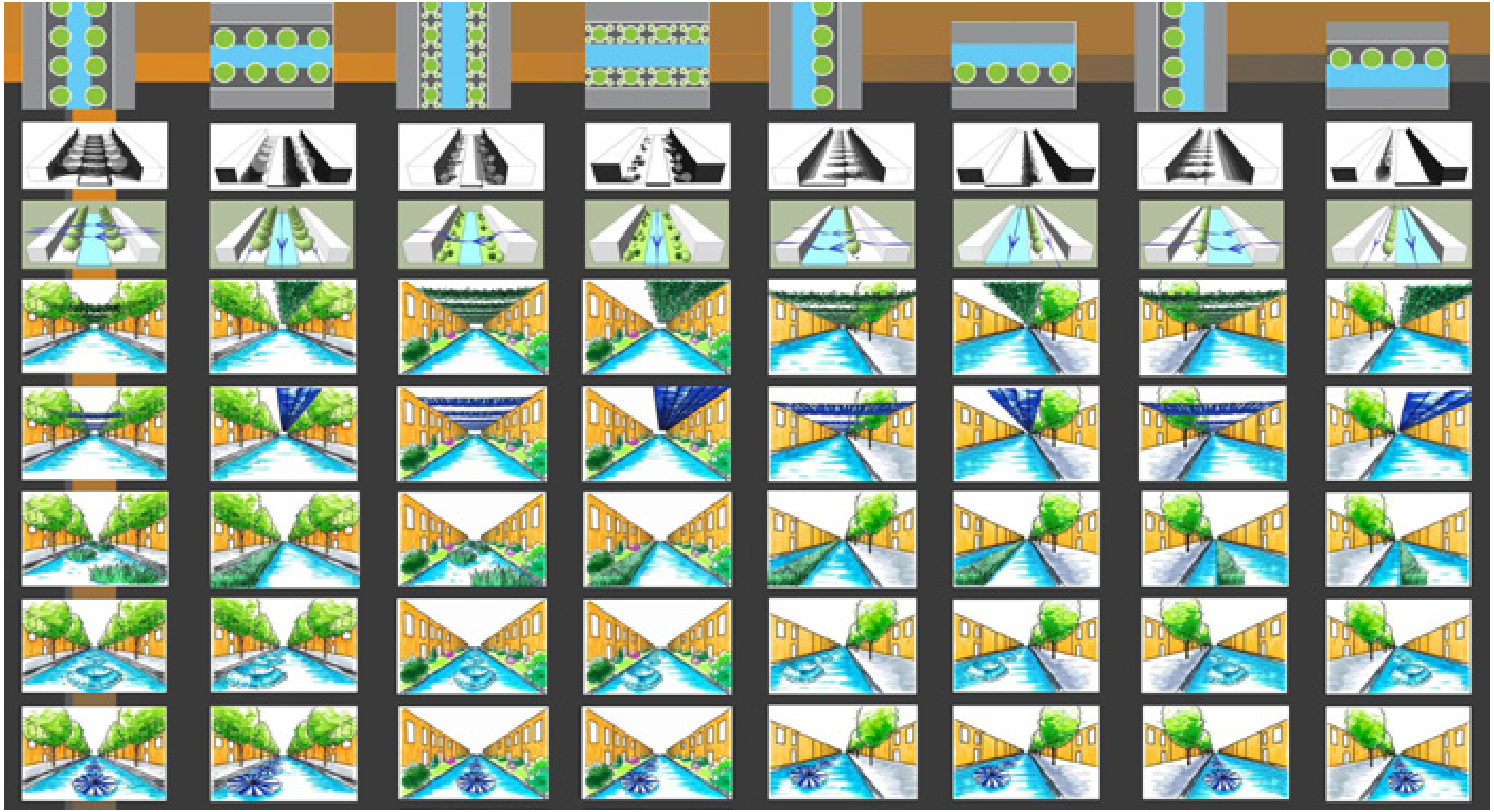


Illustration 71: Thumbnails of analyses and basic designs

6.2 Loop 2 Additively Integrated Designs

The basic designs are all single-method designs. Some of them are effective at certain mechanisms, while most of the case inevitably weakening the others. They have to be efficiently, creatively combined, in order to have a strong synergy on cooling effect.

6.2.1 Criteria of Selecting Basic Designs

The goal is to have the strongest synergy of three effects, that means to have the strongest single effects, and make them less weaken each other at the same time. Based on this fundamental criteria, an evaluating system was developed.

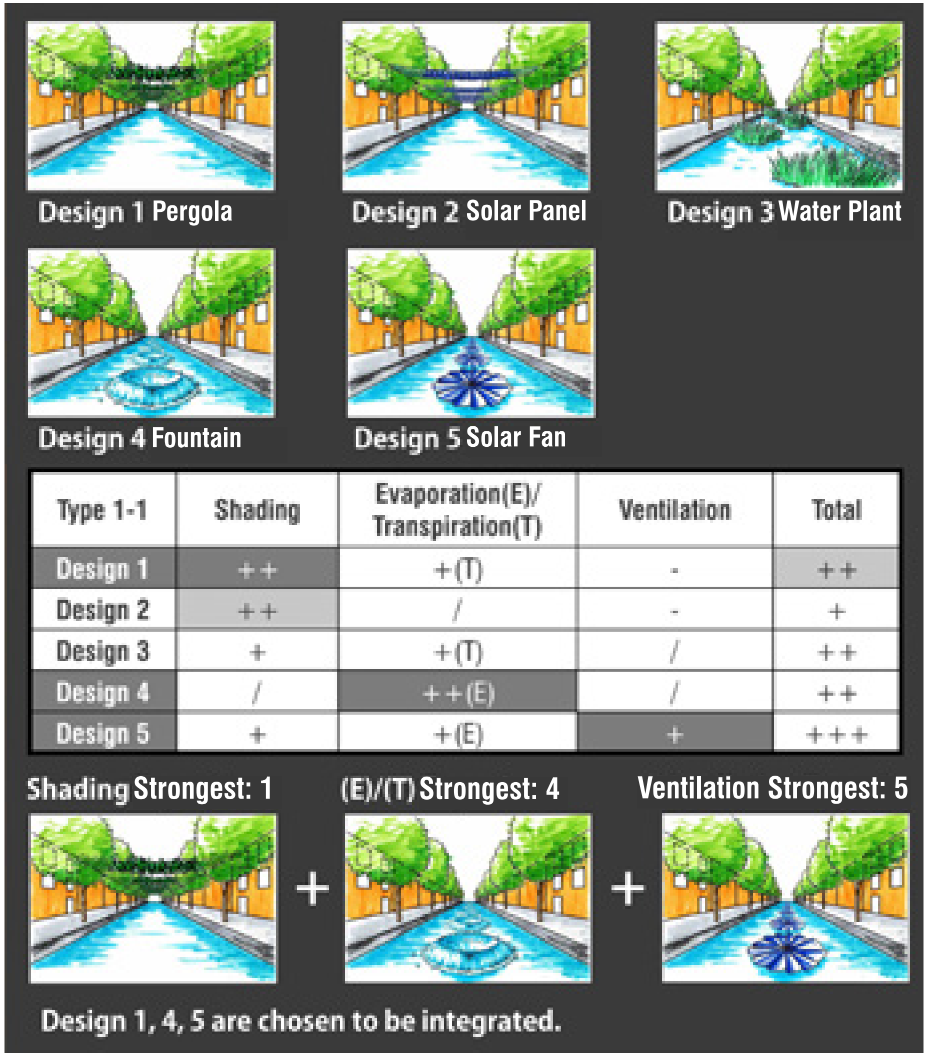
The evaluating system works basically as: comparing scores of the evaluations of basic designs on every cooling mechanism effect first, to identify the strongest design for every effect; on the other hand, also calculate the total score for every design, to see how much the strongest effect is weakening the other two. When there are more than one strongest design for one effect, compare the total score and choose the one with higher total score. Using this system, I was able to choose three basic designs each of which is strongest respectively on one of the three cooling mechanism effects, but less weakening the others, for each test-bed, and creatively combine them on cooling synergy.

6.2.2 Selecting, Integrating & Evaluating

For each test-bed, on each cooling mechanism, the score of each basic design is compared with each other in a table (Illustration 72). If there is only one design with the highest score, it is selected, both the design number and the score are marked with dark grey in the table. The sum of the scores of all three cooling mechanisms for each design is also calculated. If there are more than one designs score highest on one mechanism, the scores are marked in light grey. The sum scores will then be compared. In result, the design with higher sum score is finally chosen, and the higher sum score is marked in light grey. The final chosen design number and its highest score on that mechanism are then marked in dark grey.

The integration happens in an additive way. As the shading intervention is the with the highest priority, and relatively less flexible, the design strongest on shading is usually used as the base of the integration (there are exceptions). In this way, shading effect is first guaranteed. Evapotranspiration and ventilation interventions are combined creatively according to the cooling effect design criteria. There are situations that the criteria do not fit. The criteria are then adjusted to include the new situations. In this way, the criteria are refined.

Canal 1-1:



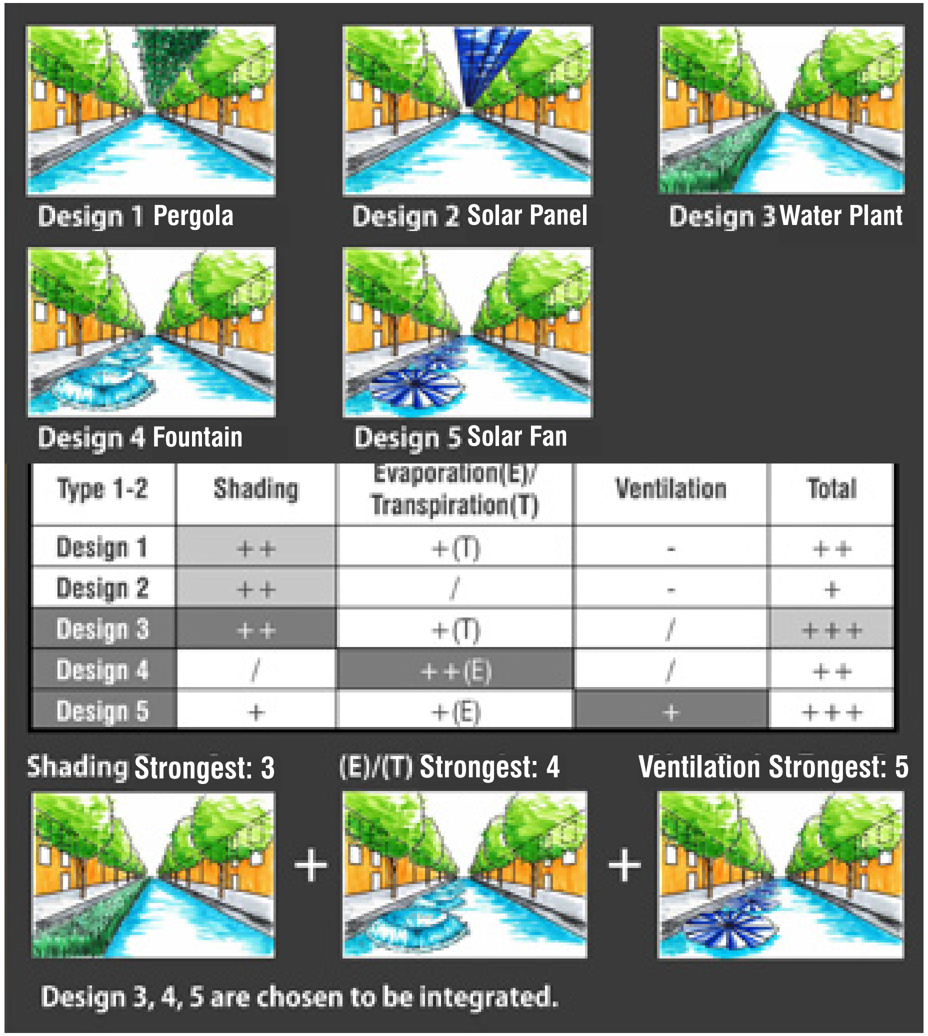
Type 1-1	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	+	+(T)	/	++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++

Illustration 72: Selecting process of Canal 1-1

Illustration 73: Additively Integrated Design of Canal 1-1

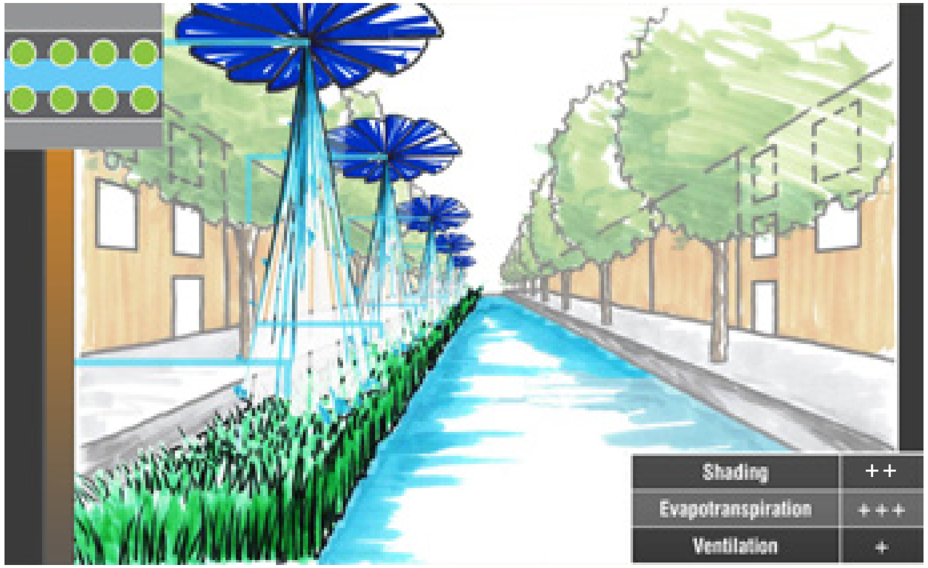
In this design, pergolas are used as the base of the integration, kept as in the basic design. However the fountains are transformed into water sprays to become more flexible. The sprays are positioned above the pergolas, so that water is more dispersed on the climbing plants in the sun to evaporate more. The solar fans are split into normal fans and solar panels on roofs of adjacent houses for two reasons: one is that the solar fans are not technically tested, and I want to use the safest option for the strongest cooling effect in additively integrated designs. So I chose the normal fan. The other reason is that when a solar fan is split in two parts, it is more flexible for positioning. The solar panels are fully in the sun, the fans are sometimes shading in the gaps of shades from both pergolas and trees. The solar energy collected is to powers both the fans and the water sprays. Fans in the middle of the canal close to water surface is the most effective position to blow up water vapor so that it is blown away by the regional wind. The ventilation is however weakened by the pergolas, so the ventilation effect is neutral compared to non-designed situation.

Canal 1-2:



Type 1-2	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	++	+(T)	/	+++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++

Illustration 74: Selecting process of Canal 1-2

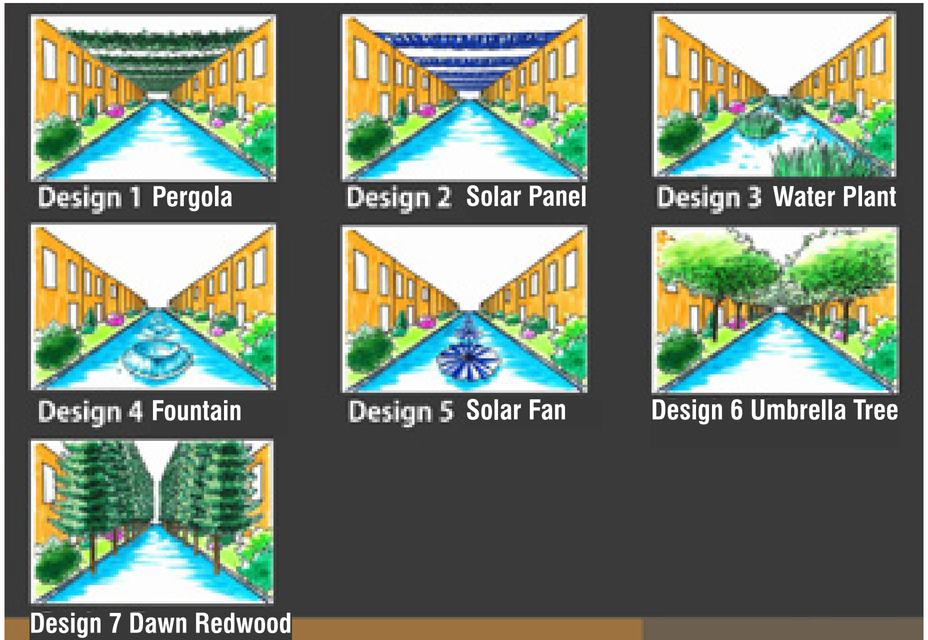


Shading	++
Evapotranspiration	+++
Ventilation	+

Illustration 75: Additively Integrated Design of Canal 1-2

In this design, water plants are planted in the northern side of the canal to shade the area that is completely exposed in sun as same as in basic design. Water plants are also transpiring. Because the wind in this test-bed is channelling to west, the water plants are barely influencing the wind. The Fountains are turned to water sprays so that they can be above the water plants in the sun to evaporate more. The solar fans are put in the sun above the water sprays, powering both themselves and the sprays. Water sprays create plenty of water vapor, solar fans draw up water vapor and blow it into regional wind.

Canal 2-1:



Type 2-1	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	++	+(T)	/	+++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++
Design 6	++	++(T)	--	++
Design 7	+	+++(T)	-	+++

Design 3, 5, 7 are chosen to be integrated.

Illustration 76: Selecting process of Canal 2-1

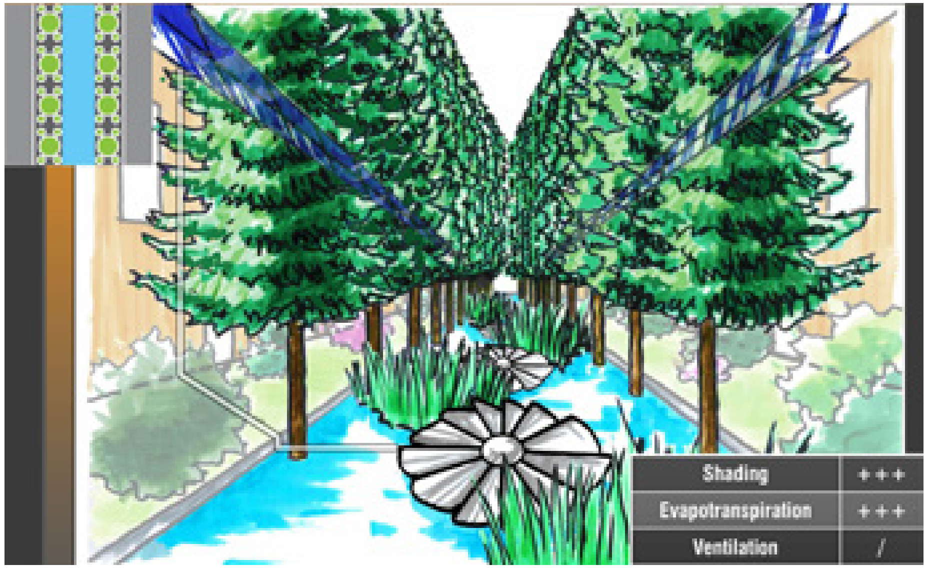
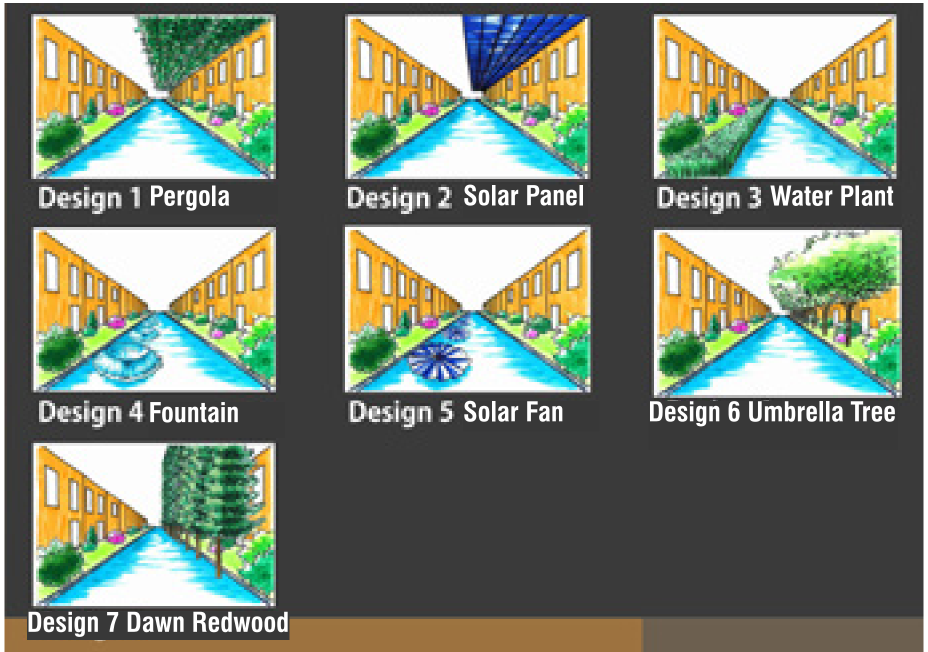


Illustration 77: Additively Integrated Design of Canal 2-1

In this integrated design, fans, Dawn Redwood and water plants are combined to shade. Both Dawn Redwoods and water plants are transpiring a lot. The solar fans are split into normal fans, and solar panels on the roofs. Grown Dawn redwood is about 15-meter tall, and the houses in the test-bed are 8 -meter tall. It seems that the shades of the trees will cover the solar panels, but with the 9-meter wide gardens, it will not happen.

Canal 2-2:



Type 2-2	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	++	+(T)	/	+++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++
Design 6	++	++(T)	--	++
Design 7	+	+++(T)	-	+++

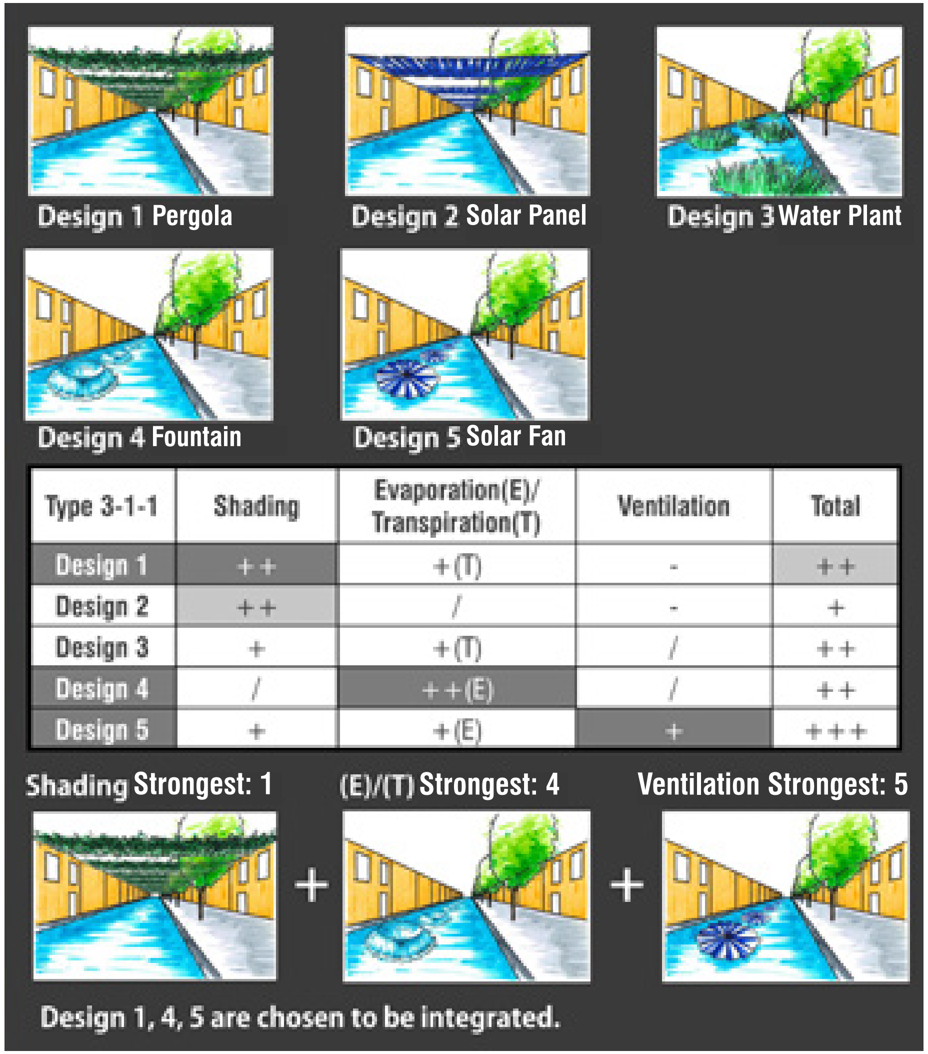
Design 3, 5, 7 are chosen to be integrated.

Illustration 78: Selecting process of Canal 2-2

Illustration 79: Additively Integrated Design of Canal 2-2

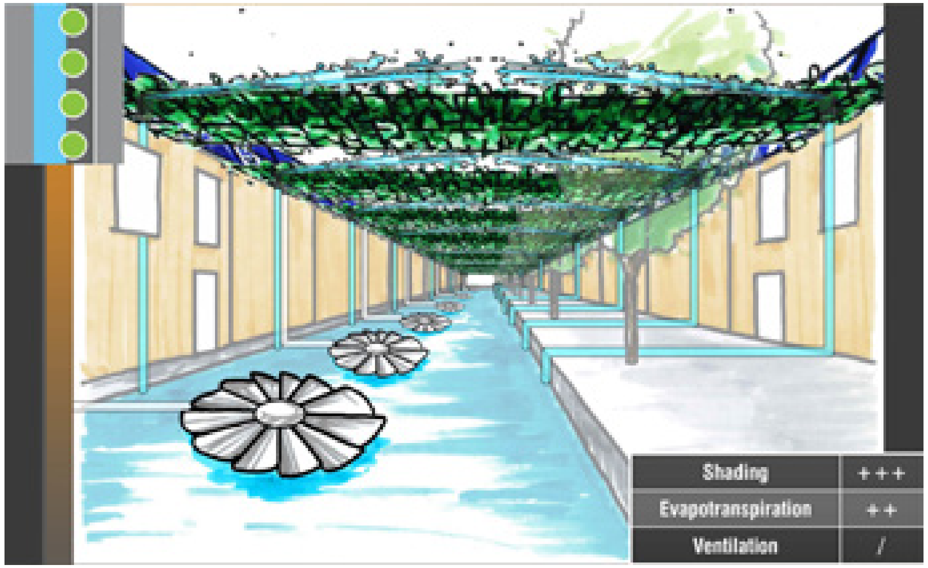
In this design, since the Dawn Redwoods are quite tall, only one row of them on the southern side of the canal is needed for shading. Water plants and fans are positioned in the gaps of the shadows of the trees to shade. Both Dawn Redwoods and water plants transpire efficiently. Fans ventilate the water vapor and cooled air to the regional wind.

Canal 3-1-1:



Type 3-1-1	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	+	+(T)	/	++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++

Illustration 80: Selecting process of Canal 3-1-1

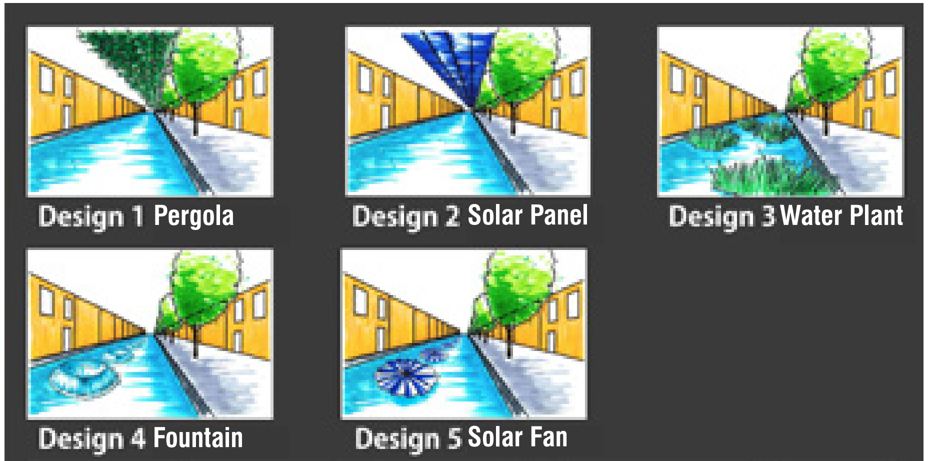


Shading	+++
Evapotranspiration	++
Ventilation	/

Illustration 81: Additively Integrated Design of Canal 3-1-1

This design is similar to Canal 1-1's, because the shadow and wind behaviors are similar. The pergolas are as same as in the basic design as the base of the integration. The fountains are transformed into water sprays to become more flexible. The sprays are positioned above the pergolas, so that water is more dispersed on the climbing plants in the sun to evaporate more. The solar fans are split into normal fans and solar panels on roofs of adjacent houses. Fans in the gaps of the shadows of the trees and houses are shading and blowing up water vapor so that it is blown away by the regional wind. The ventilation is however weakened by the pergolas, so the ventilation effect is neutral compared to non-designed situation.

Canal 3-1-2:



Type 3-1-2	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	+	+(T)	/	++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++

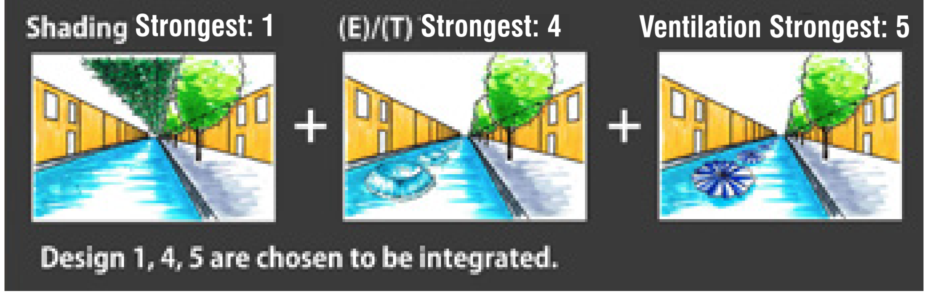
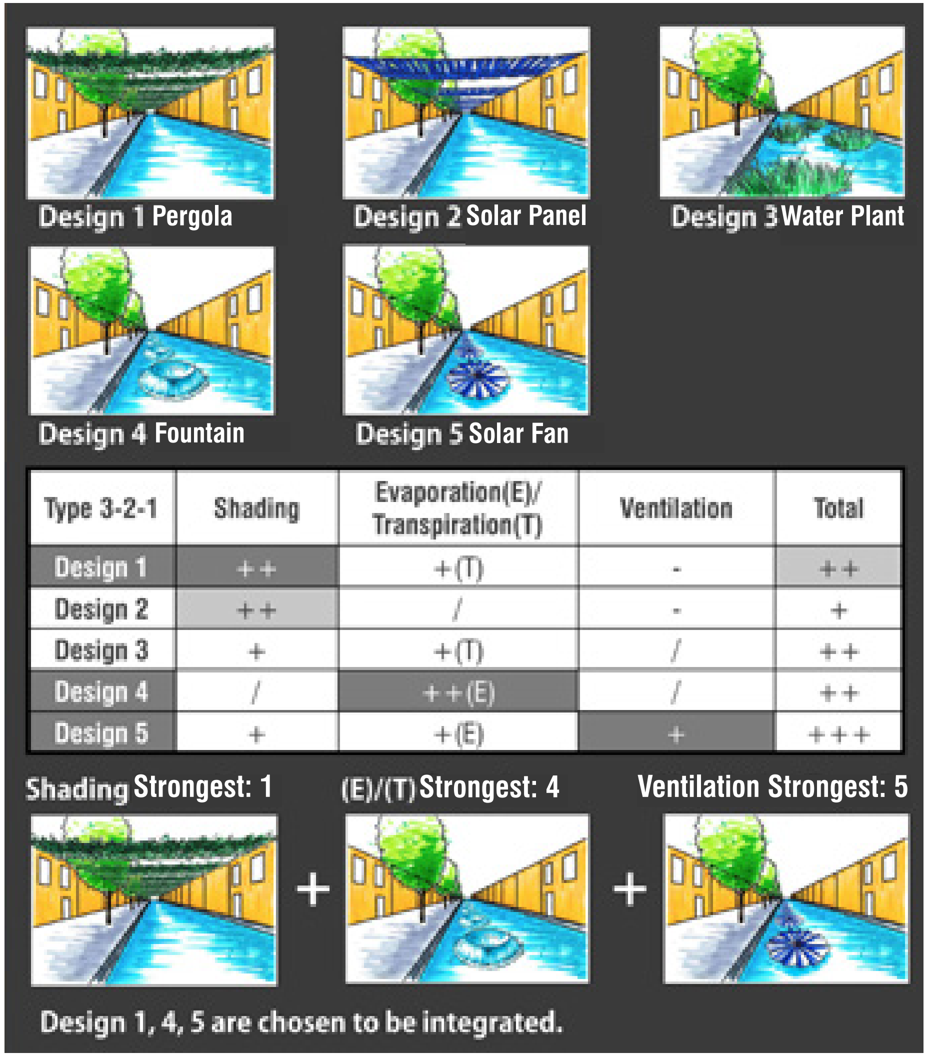


Illustration 82: Selecting process of Canal 3-1-2

Illustration 83: Additively Integrated Design of Canal 3-1-2

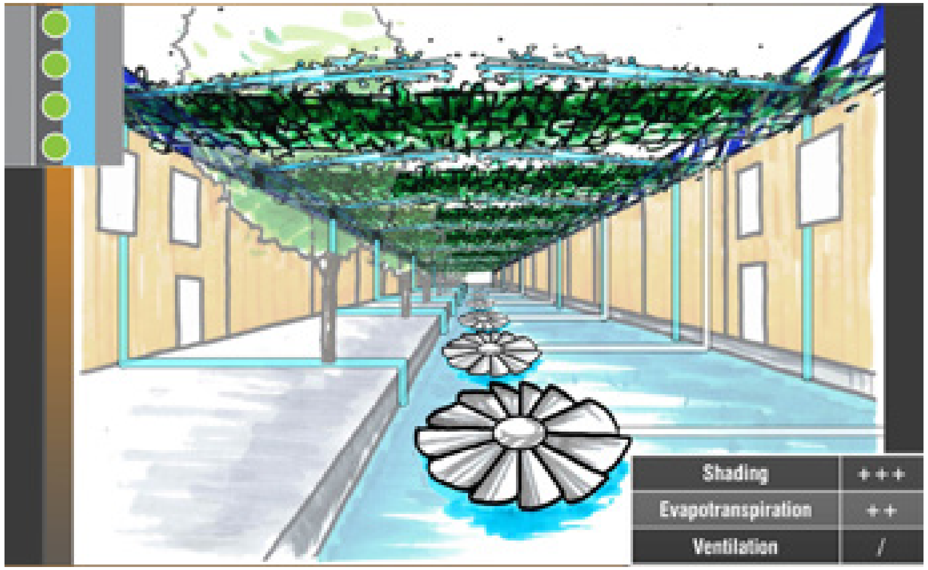
This test-bed's shadow and wind behaviors are similar to Canal 1-2's, However the integrated design is different from Canal 1-2's is because, the trees in this canal type are too small, and that leaves too large canal surface completely exposed in sun. If this test-bed also use water plants to mainly shade, the canal will be full of water plants. So this test-bed use pergolas to shade. The water sprayed onto the pergolas is more dispersed on the plants in sun and evaporate more. Fans use solar energy from the solar panels on the roofs to ventilate and compensate the ventilation weakened by the pergolas.

Canal 3-2-1:



Type 3-2-1	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	+	+(T)	/	++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++

Illustration 84: Selecting process of Canal 3-2-1

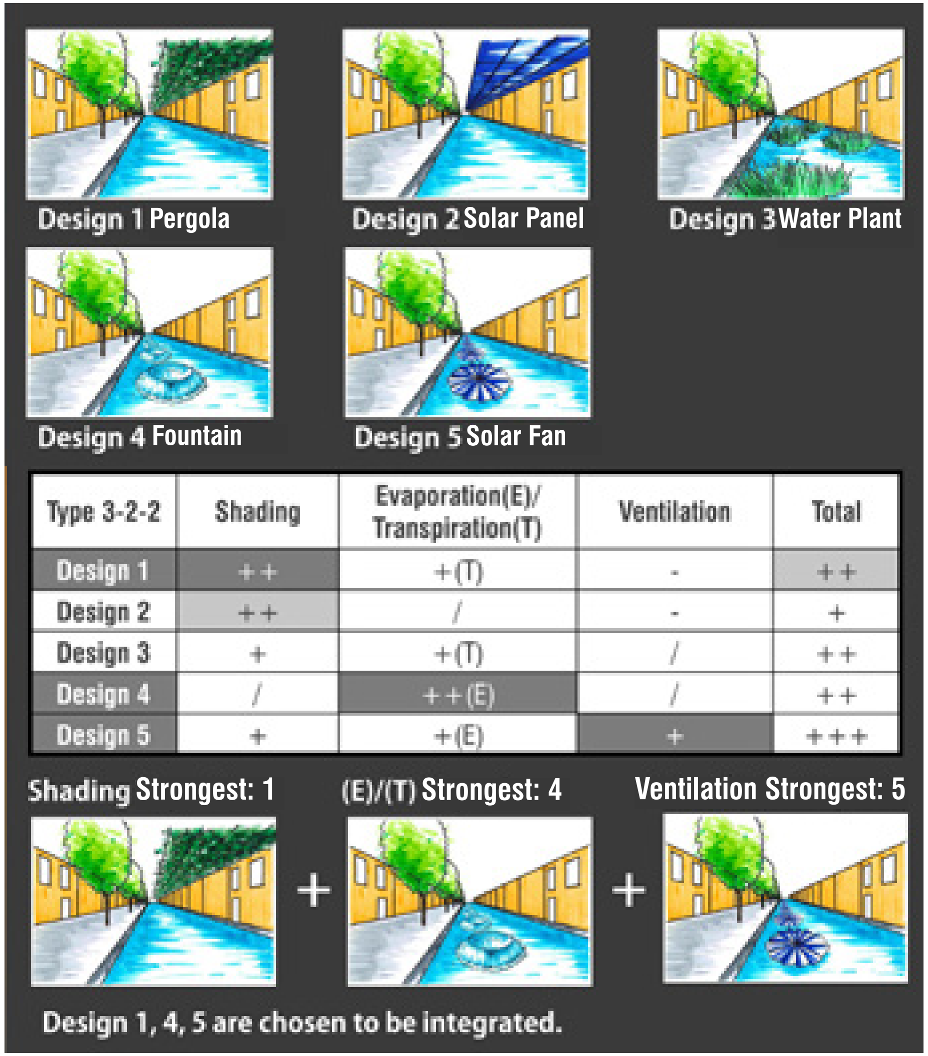


Shading	+++
Evapotranspiration	++
Ventilation	/

Illustration 85: Additively Integrated Design of Canal 3-2-1

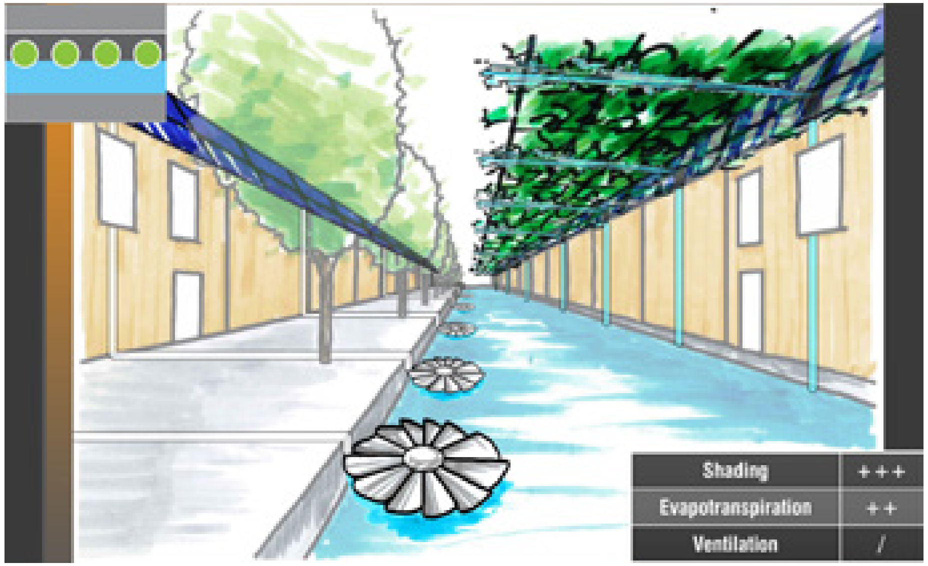
For the same reasons as Canal 3-1-1, this test-bed's situation is also similar to Canal 1-1. Interventions in this integrated design are only a little adjusted from the positions in the Integrated Design of Canal 1-1. The evaluation results are also the same.

Canal 3-2-2:



Type 3-2-2	Shading	Evaporation(E)/ Transpiration(T)	Ventilation	Total
Design 1	++	+(T)	-	++
Design 2	++	/	-	+
Design 3	+	+(T)	/	++
Design 4	/	++(E)	/	++
Design 5	+	+(E)	+	+++

Illustration 86: Selecting process of Canal 3-2-2



Shading	+++
Evapotranspiration	++
Ventilation	/

Illustration 87: Additively Integrated Design of Canal 3-2-2

This canal type's situation is a lot similar to Canal 3-1-2. Only instead of the shades of the trees, the shades of the houses shade the canal. Interventions in this integrated design are only a little adjusted from the positions in the Integrated Design of Canal 3-1-2. The evaluation results are also the same.

6.2.3 Refined Cooling Effect Design Criteria

Through the process of Additively Integrated Design, it can be seen that the Cooling Effect Design Criteria should be adjusted when being applied to multiply combined interventions, because interventions also influence each other.

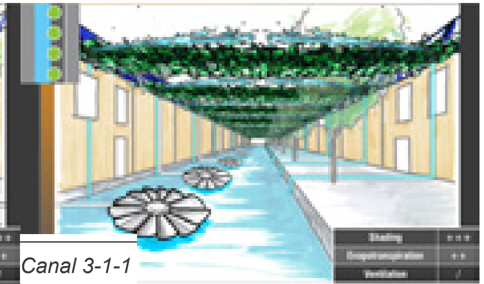
For shading mechanism, the criteria are barely changed, only the dynamics of the shades of the shading interventions in different hours of the day should be paid attention on. For evapotranspiration mechanism, as the areas of the canal that were exposed fully in sun are shaded by shading interventions, the former criteria do not apply anymore. The new criteria are, the evapotranspiration interventions should be exposed in sun as much as possible near the canal, ideally also be near the ventilation. The new ventilation criteria are, the ventilation should be through the evapotranspiration interventions to be able to efficiently blow away the water vapor; and the ventilation interventions should not be against the wind, should be able to be integrated with the wind.

6.3 Loop 3 Free-style Form Designs

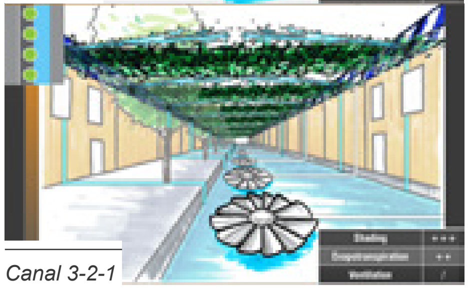
The Additively Integrated Designs are only concerned about the cooling effect of the canals, as designs they also have to have proper forms, not only satisfying the functions, but also for aesthetic experience and recreation. In this loop I try to explore the limit of the forms of the Additively Integrated Designs. I try to think out of the box and push the forms to extremes.

It was already stated that the Additively Integrated Designs of Canal 3-1-1 and 3-2-1 are similar to the one of Canal 1-1. There are 3 of them in total 8 Additively Integrated Designs for, so I chose the form of Additively Integrated Design of Canal 1-1 as a representative form, to do this loop.

Canal 1-1



Canal 3-1-1



Canal 3-2-1

Illustration 88: The three similar Additively Integrated Designs of Canal 1-1, 3-1-1, 3-2-1

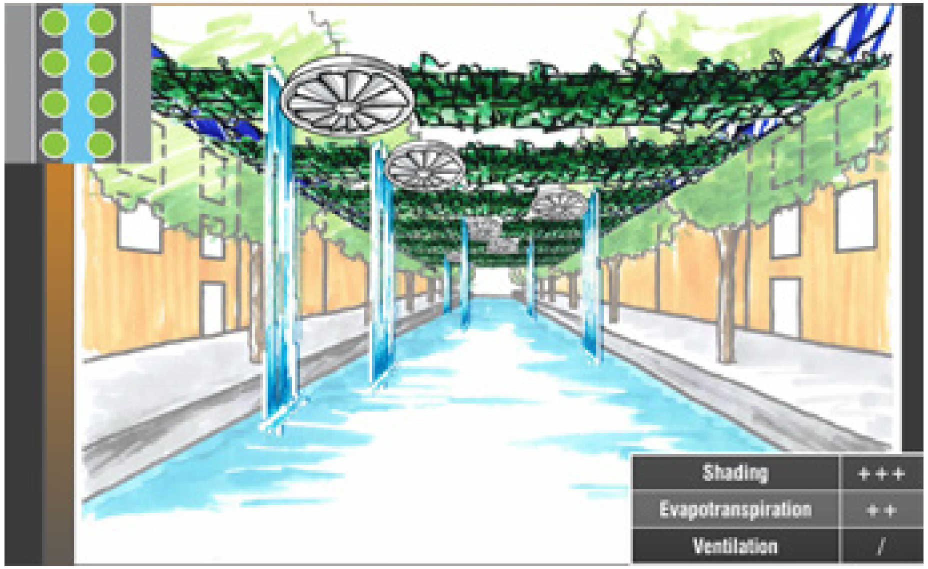


Illustration 89: The Water Fall Pergola Design of Canal 1-1

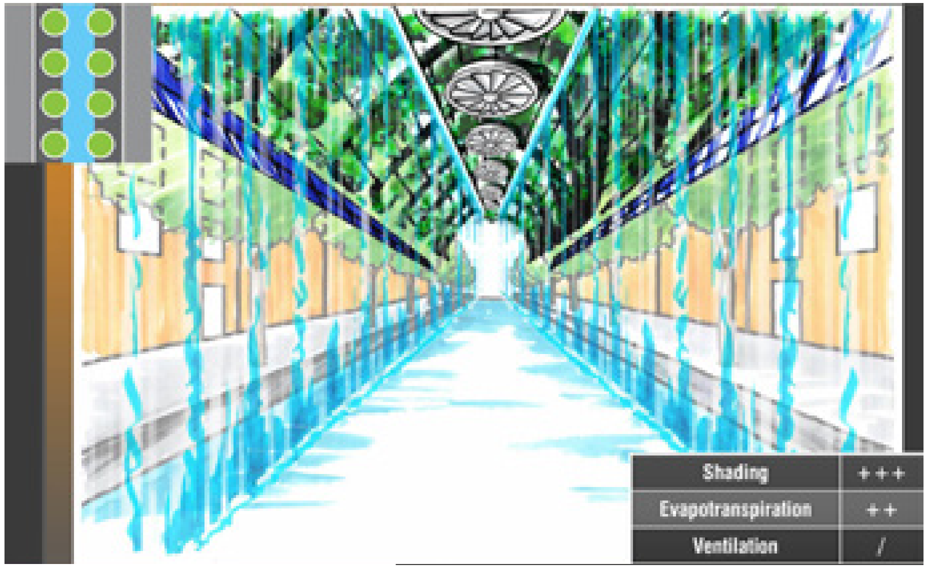


Illustration 90: The Arched Pergola Design of Canal 1-1

The first design, Water Fall Pergola, is relatively conservative as a form exploration. I embedded the fans in pergolas, and changed sprays into water falls. Water falls and fans are powered by solar panels on the adjacent roofs. The cooling effect is more or less the same. The view of the randomly arranged water falls is the highlight.

Arched Pergola Design made a breakthrough by making the pergolas spatial, not only on one horizontal face. The water falls come from the top of the arch, powered by the solar panels on the roofs of the houses nearby. The fans also get energy from the solar panels, and ventilate in the middle of the arch. More amount of water falls compensate the evaporation weakened by the fully shaded cool area. The cooling effect remains the same.

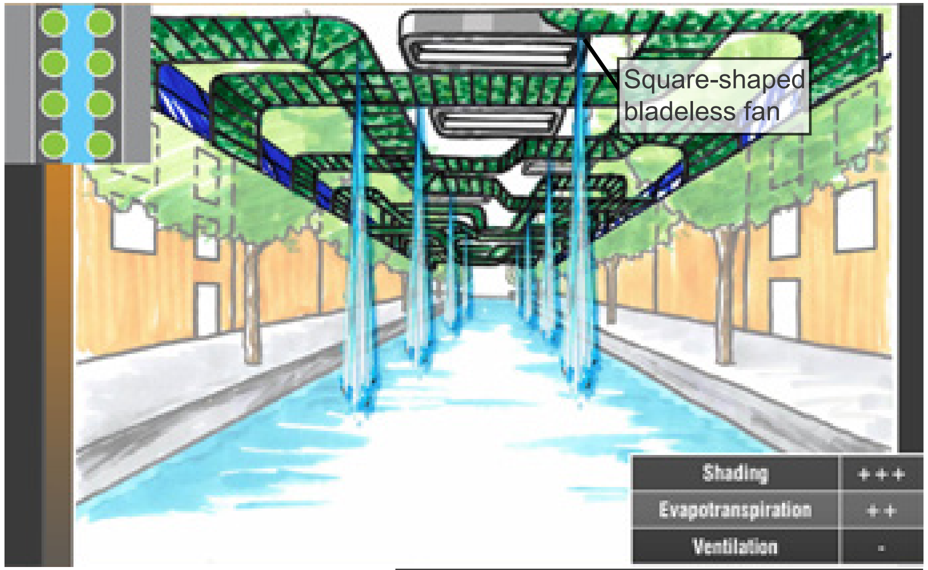


Illustration 91: The Puzzle Pergola Design of Canal 1-1

Illustration 92: Mechanism of bladeless fans (www.dailymail.co.uk)

Puzzle Pergola Design applied a more complicated spatial form of pergolas. The square-shaped bladeless fan is applied (Illustration 92). The puzzle-shaped pergolas are more like a “sculpture” in form. Water is sprayed from the “puzzle” at random points. Solar panels on the roofs are powering both the sprays and the fans. It is suspected that the square-shaped bladeless fans are not as powerful as normal fans on ventilating, so it is “-” on ventilation evaluation.

Compared to normal fan, bladeless fan has these advantages:

- More steady wind flow
- Less noise
- No annoying turning shade of blades
- More free in shapes

As an exploration of form, bladeless fans are used to free the rounded-shape of normal fans.

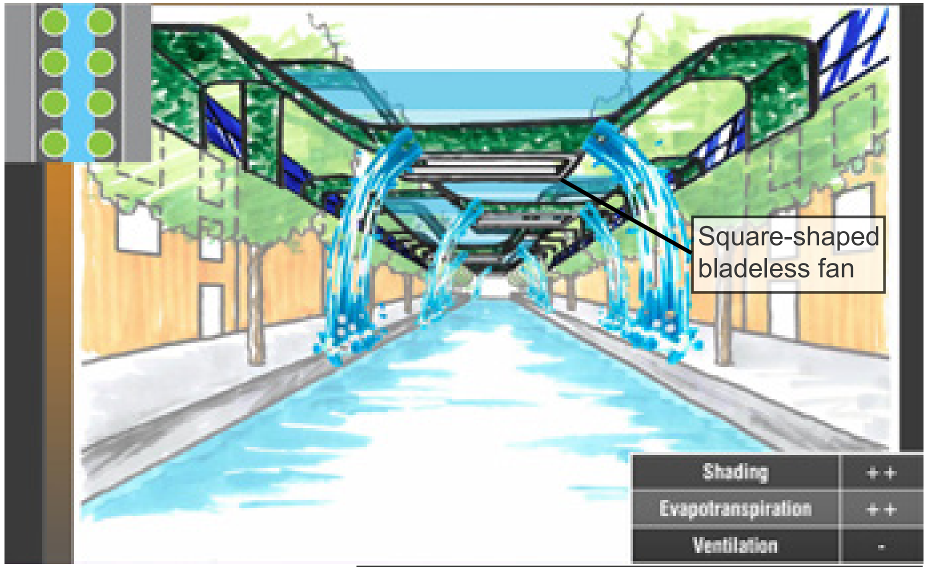


Illustration 93: The Water Tank Pergola Design of Canal 1-1

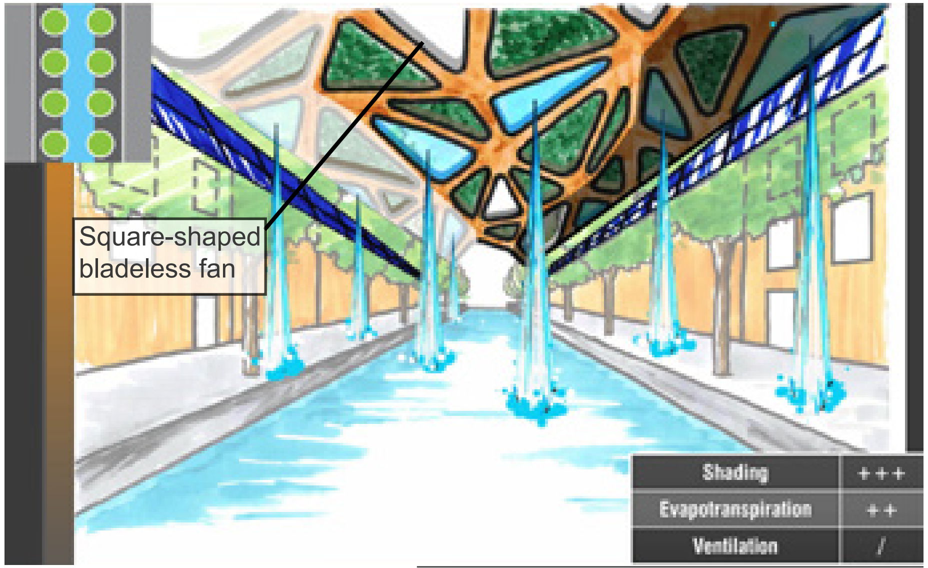


Illustration 94: The Web Pergola Design of Canal 1-1

Water Tank Pergola Design integrates water tanks with the pergolas to store rain water and create water falls. Square-shaped bladeless fan is again applied here. However the shading is not so effective anymore because of the thin shapes of the pergolas. And for the same reason as the Puzzle Pergola Design, the ventilation is also compromised.

The last Web Pergola Design is the boldest one. It uses an arching roof to cover the canal, and dividing the roof into triangles, which looks like a web. Some of the triangles are used as triangle-shaped bladeless fans. Some are used as water tanks to store rain water and create water falls. Some are used to grow plants to shade and transpire. Water falls and fans use energy from the solar panels on the neighboring roofs. It manages to maintain the cooling effect of the original Additively Integrated Design.

From all the Free-style Form Designs, it goes from conservative to radical in the form of design. The Arched Pergola Design is neither too ordinary nor too extra-ordinary, it is chosen as the form to be combined with the Additively Integrated Designs (if applicable) in the final designs.

6.4 Feasibility Evaluations

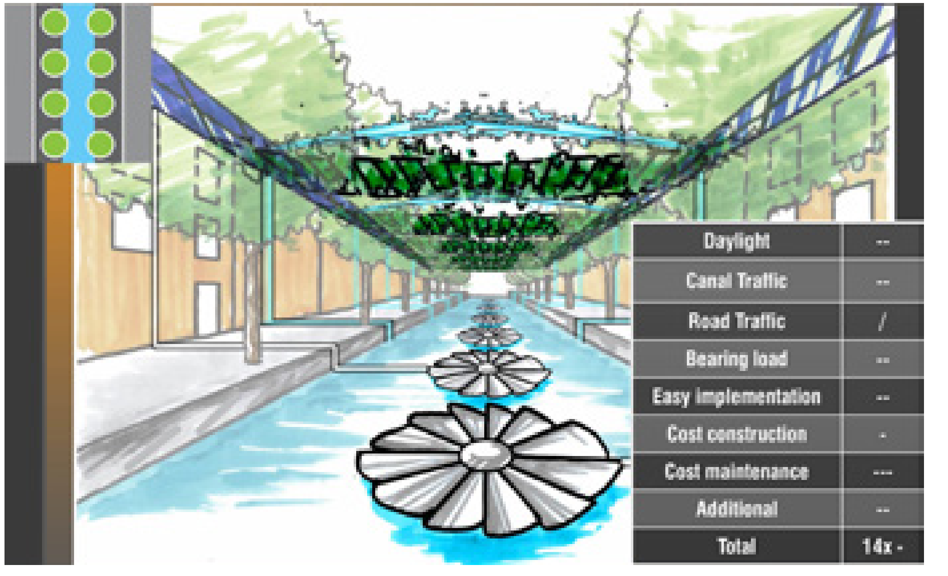
Although the cooling effect and forms of the integrated designs are explored, there are still other pragmatic issues to be taken into consideration, to have feasible final design and principles. The following Feasibility Design Criteria are taken into account:

- **Daylight**: daylight intrusion in houses is very crucial to the everyday life of residence living around the canal. The cooling interventions shall block as less sunlight for the adjacent house as possible.
- **Canal Traffic**: space for small vessels to travel is necessary for the canals. As observed, people enjoy recreational canoeing in the canals.
- **Road Traffic**: space for traffic and parking is important. As observed, usually space beside the canals is used as parking lots if there are roads beside the canal.
- **Bearing Load**: bearing load of the houses should be taken into account if the cooling interventions are attached onto the house adjacent. As observed, the house in Utrecht are usually old house with not much capacity of extra bearing load.
- **Easy Implementation**: whether the interventions are in public or private space is vital for implementation. If it is in private space, it is quite hard to convince the house holders. Also if it is in place where it is hard to implement interventions, like in the middle of a canal, it is less feasible.
- **Cost Construction**: the budget of the interventions is sure limited, the lower the cost, the more the feasibility.
- **Cost Maintenance**: the same as above. Plus energy sustaining and even extra energy providing make it cheaper to maintain.
- **Additional**: other environmental, and recreational considerations, like preventing the noise, providing the picturesque view, providing the approach of water, providing phone charging facilities, etc.

Again, the evaluating symbols “+”, “-”, “/” represent enhancing, weakening, and neutral respectively compared to the original situation. Although the nature of the aforementioned factors determined that “+” is barely applicable in feasibility evaluation.

6.4.1 Feasibility Evaluations of Additively Integrated Designs

Canal 1-1:



Daylight	--
Canal Traffic	--
Road Traffic	/
Bearing load	--
Easy implementation	--
Cost construction	-
Cost maintenance	---
Additional	--
Total	14x -

Illustration 95: Feasibility evaluation of Additively Integrated Design for Canal 1-1

- Daylight: in this design, the sunlight is largely blocked by the pergolas not only for the canal, but also for the adjacent houses in summer. In winter the climbing plants here should be deciduous and leafless, the influence is then negligible. The “- -” is for the summer situation.
- Canal Traffic: the “- -” is for that the fans in the middle of the canal is very disturbing for canal traffic.
- Road Traffic: in this case, the road traffic is not influenced, so it’s neutral “/”.

- Bearing Load: the pergolas and the added solar panels are adding the bearing load of the houses, so the evaluation is “- -”.
- Easy Implementation: the fans in the middle of the canal are quite difficult to implement, so the evaluation is “- -”.
- Cost Construction: all the components in the design can be easily bought for reasonable prices, so the evaluation is “-”.
- Cost Maintenance: The climbers of the pergolas need to be trimmed regularly. It is hard to repair the fans in the middle of the canal if anything goes wrong. The water sprays also need maintenance regularly. So the evaluation is “- - -”.
- Additional: the fans and water sprays may create constant unpleasant noise, so the evaluation is “- -”.

Canal 1-2:

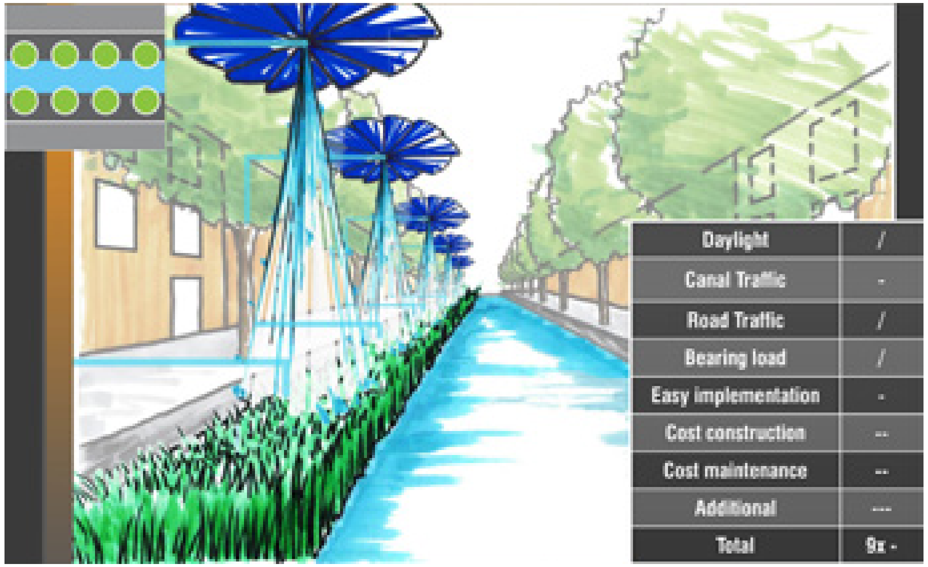


Illustration 96: Feasibility evaluation of Additively Integrated Design for Canal 1-2

- Daylight: in this design the sunlight is only blocked for the canal. And the shadows of the fans cannot reach the houses, so the evaluation is “/”.
- Canal Traffic: the “-” is for that the water plants on the side of the canal is narrowing down the canal, so they are stemming canal traffic.
- Road Traffic: in this case road traffic is not influenced, so the evaluation is neutral “/”.
- Bearing Load: because the fans are not on the houses, the evaluation is “/”.
- Easy Implementation: both the fans and the water plants are on the side of the canal, which are easier to implement than in the middle, so the evaluation is “-”.
- Cost Construction: the “solar fan” is not available on the current market, it has to be specially designed and produced, so the evaluation is “- -”.
- Cost Maintenance: The water plants need to be trimmed regularly. It is easier to repair the fans on the side of the canal. The water sprays need maintenance regularly. The evaluation is “- -”.
- Additional: the fans may create constant unpleasant noise and turning shades. The water sprays may also create unpleasant noise to certain people, so the evaluation is “- - -”.

Canal 2-1:

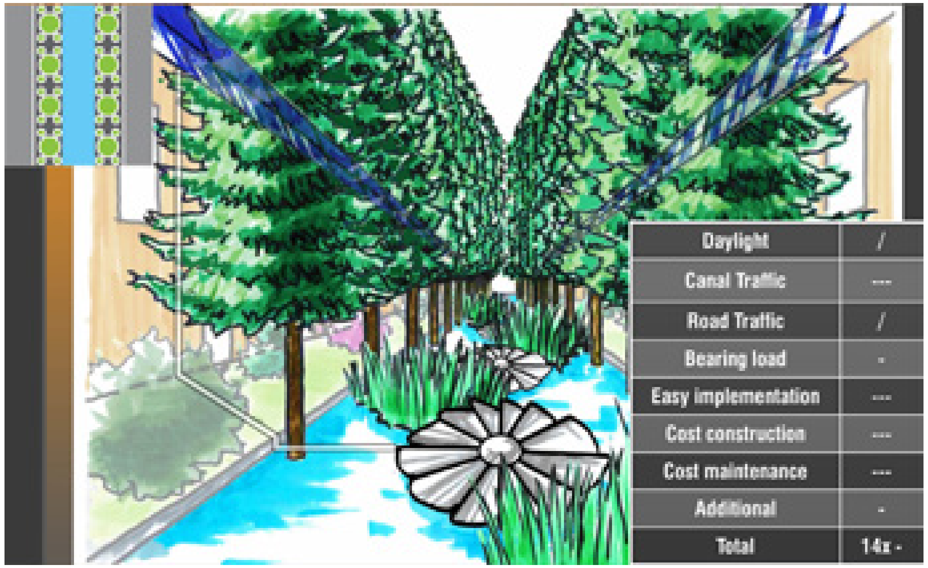


Illustration 97: Feasibility evaluation of Additively Integrated Design for Canal 2-1

- Daylight: in this design, the sunlight is largely blocked by the trees not only for the canal, but also for the houses in summer. In winter the trees are leafless, the influence is negligible. The "- -" is for the summer.
- Canal Traffic: the "- - -" is for that the fans in the middle of the canal together with the water plants growing there are very disturbing for canal traffic.
- Road Traffic: in this case there is no traffic, so the evaluation is neutral "/".
- Bearing Load: only the added solar panels are adding the bearing load of the houses, it's not much, so the evaluation is "-".
- Easy Implementation: the fans in the middle of the canal are quite difficult to implement. And the trees are very close to the private gardens, the neighbors may not like them, so the evaluation is "- - -".
- Cost Construction: the dawn redwood trees are expensive, worth 2 "-"s. All the other components in the design can be easily bought for reasonable prices, so in total the evaluation is "- - -".
- Cost Maintenance: The trees and water plants need to be trimmed regularly. And it is hard to repair the fans in the middle of the canal if anything goes wrong. The evaluation is "- - -".
- Additional: the fans may create constant unpleasant noise, so the evaluation is "-".

Canal 2-2:

Illustration 98: Feasibility evaluation of Additively Integrated Design for Canal 2-1

- Daylight: in this design the sunlight is only blocked for the canal, because it is tested in model that the matured Dawn Redwood's shadow will not reach the houses, so the evaluation is "/".
- Canal Traffic: the "- - -" is for that the fans in the side of the canal together with the water plants growing there are very disturbing for canal traffic.
- Road Traffic: in this case there is no traffic, so the evaluation is neutral "/".
- Bearing Load: only the added solar panels are adding the bearing load of the buildings, so the evaluation is "-".
- Easy Implementation: the fans are on a side of the canal, which are easy to implement. But the trees are very close to the private gardens, the neighbors may not like them, so the evaluation is "- -".

- Cost Construction: the dawn redwood trees are expensive, worth 2 “-”s. All the other components in the design can be easily bought for reasonable prices, so in total the evaluation is “- - -”.
- Cost Maintenance: The trees and water plants need to be trimmed regularly, but it is easy to repair the fans in the middle of the canal if anything goes wrong, so the evaluation is “- -”.
- Additional: the fans may create constant unpleasant noise, so the evaluation is “-”.

Canal 3-1-1:

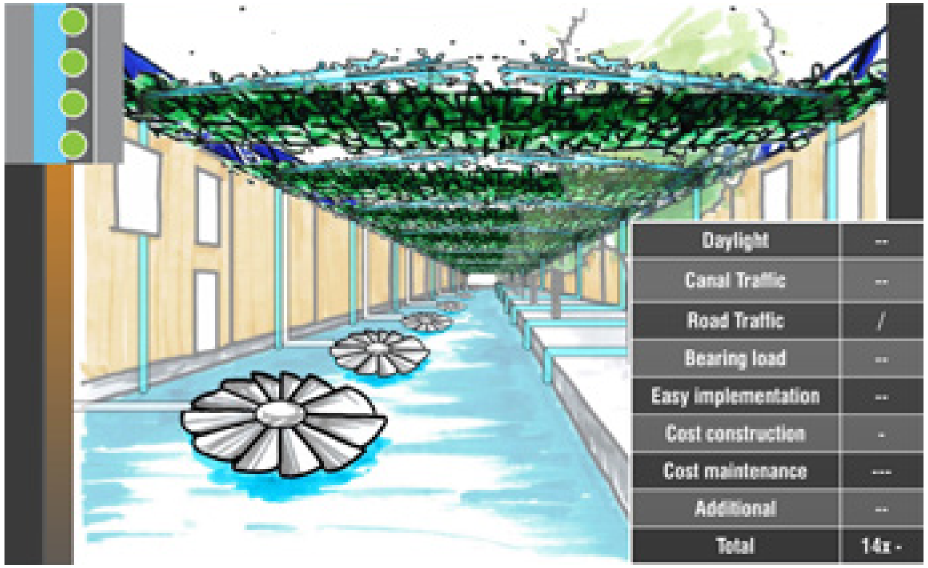


Illustration 99: Feasibility evaluation of Additively Integrated Design for Canal 3-1-1

Additively Integrated Design of Canal 3-1-1 is very similar to the one of Canal 1-1. The little difference between the two is not enough to alter any of the feasibility evaluation results. For detailed description see Canal 1-1’s Additively Integrated Design feasibility evaluation.

Canal 3-1-2:

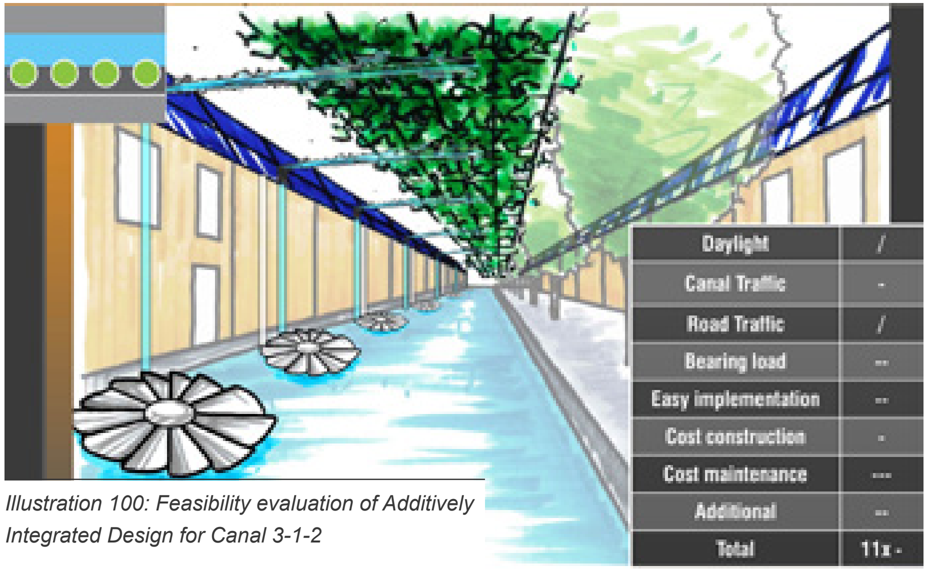


Illustration 100: Feasibility evaluation of Additively Integrated Design for Canal 3-1-2

- Daylight: in this design the sunlight is blocked by the pergolas only for the canal, so the evaluation is “/”.
- Canal Traffic: the “-” is for that the fans are on a side of the canal, which is less disturbing for canal traffic.
- Road Traffic: in this case road traffic is not influenced, so the evaluation is neutral “/”.
- Bearing Load: the pergolas and the added solar panels are adding the bearing load of the houses, so the evaluation is “- -”.
- Easy Implementation: the fans far from the canal bank are quite difficult to implement, so the evaluation is “- -”.
- Cost Construction: all the components in the design can be easily bought for reasonable prices, so the evaluation is “-”.
- Cost Maintenance : The climbing plants of the pergola needs to be trimmed regularly. It is hard to repair the fans far from the canal bank if anything goes wrong. The water sprays also need regular maintenance, so the evaluation is “- - -”.
- Additional: the fans and water sprays may create constant unpleasant noise, so the evaluation is “- -”.

Canal 3-2-1:

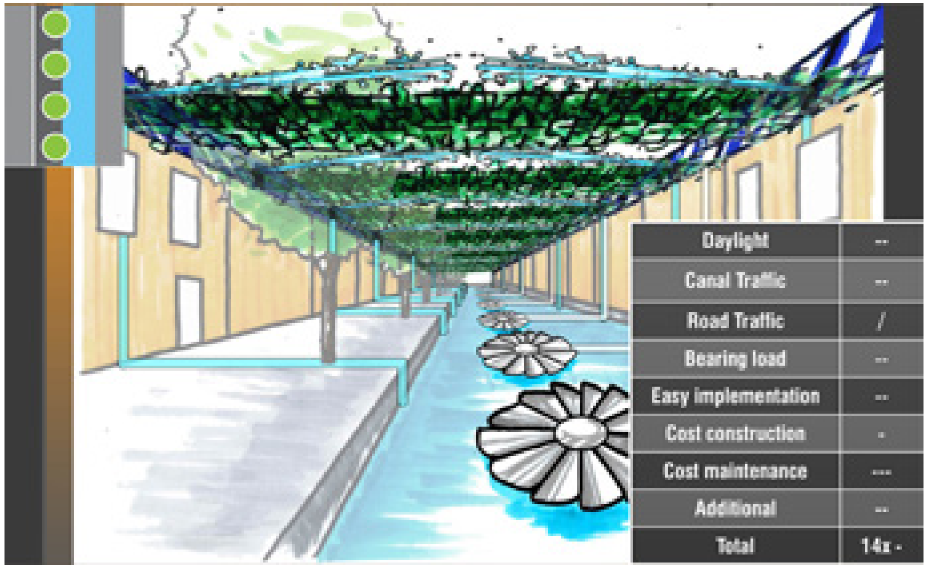


Illustration 101: Feasibility evaluation of Additively Integrated Design for Canal 3-2-1

For the same reason as Canal 3-1-1, this test-bed's Additively Integrated Design is very similar to the one of Canal 1-1, so are their feasibility evaluation results. For detailed descriptions, see Canal 1-1's Additively Integrated Design's feasibility evaluation.

Canal 3-2-2:

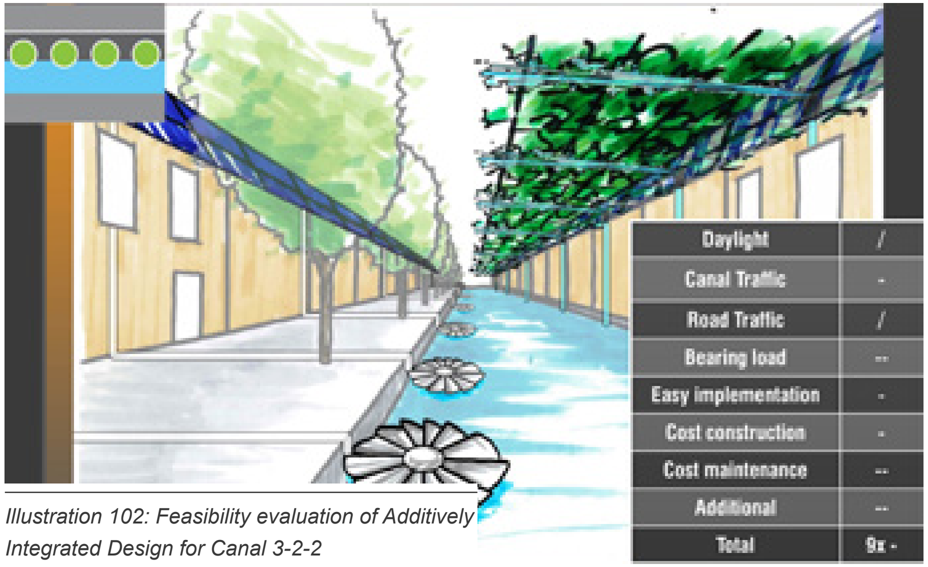


Illustration 102: Feasibility evaluation of Additively Integrated Design for Canal 3-2-2

- Daylight: in this design the sunlight is blocked by the pergolas only for the canal, so the evaluation is "/".
- Canal Traffic: the "-" is for that the fans are on the side of the canal, which is less disturbing for canal traffic.
- Road Traffic: in this case road traffic is not influenced, so it's neutral"/".
- Bearing Load: the pergola and the added solar panels are adding the bearing load of the houses, so it's "- -".
- Easy Implementation: the fans close to the canal bank are quite easy to implement, so the evaluation is "-".
- Cost Construction: all the components in the design can be easily bought for reasonable prices, so the evaluation is "-".
- Cost Maintenance : The climbing plants of the pergolas need to be trimmed regularly. It is easier to repair the fans close to the canal bank if anything goes wrong. The water sprays need maintenance regularly. So the evaluation is "- -".
- Additional: the fans and water sprays may create constant unpleasant noise, so the evaluation is "- -".

6.4.2 Feasibility Evaluations of Free-style Form Designs

Water Fall Pergola Design:

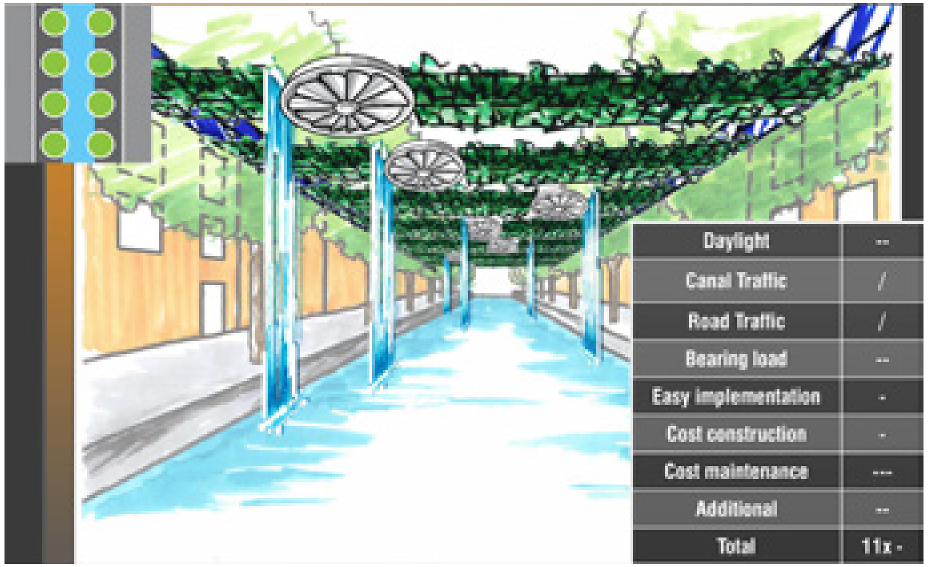


Illustration 103: Feasibility evaluation of Water Fall Pergola Design of Canal 1-1

- Daylight: in this design, the sunlight is largely blocked by the pergolas not only for the canal, but also for the adjacent houses in summer. In winter the climbing plants here should be deciduous and leafless, the influence is then negligible. The "- -" is for the summer situation.
- Canal Traffic: the canal traffic is slightly influenced by the water falls, but it is negligible, so the evaluation is "/".
- Road Traffic: in this case the road traffic is not influenced, so the evaluation is neutral "/".
- Bearing Load: the pergolas and the added solar panels are adding the bearing load of the houses, so the evaluation is "- -".
- Easy Implementation: all the components are not difficult to implement, so the evaluation is "-".
- Cost Construction: all the components in the design can be easily bought for reasonable prices, so the evaluation is "-".
- Cost Maintenance: The climbing plants of the pergolas need to be trimmed regularly. It is hard to repair the fans on the pergolas if anything goes wrong. The water falls also need regular maintenance, so the evaluation is "- - -".
- Additional: the fans and water falls may create constant unpleasant noise, so the evaluation is "- -".

Arched Pergola Design:

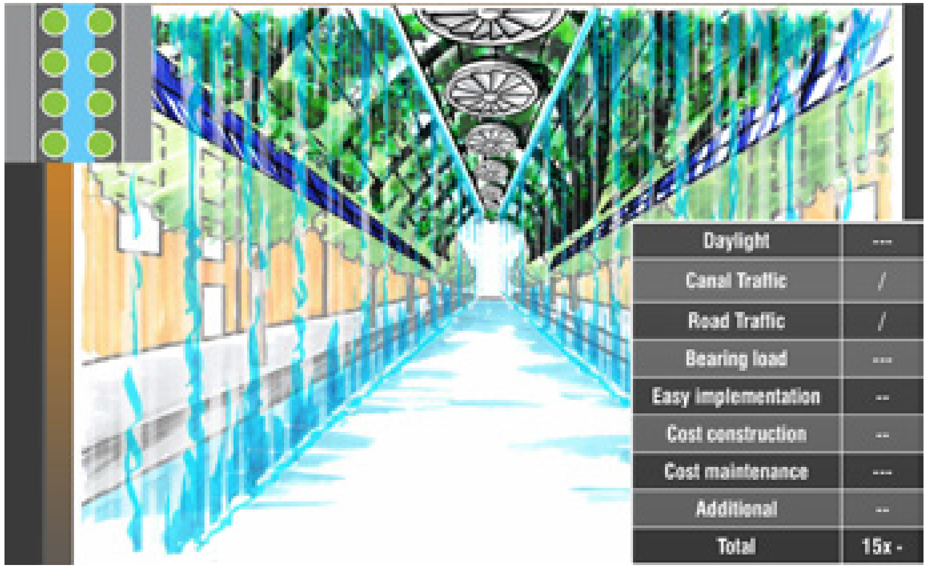
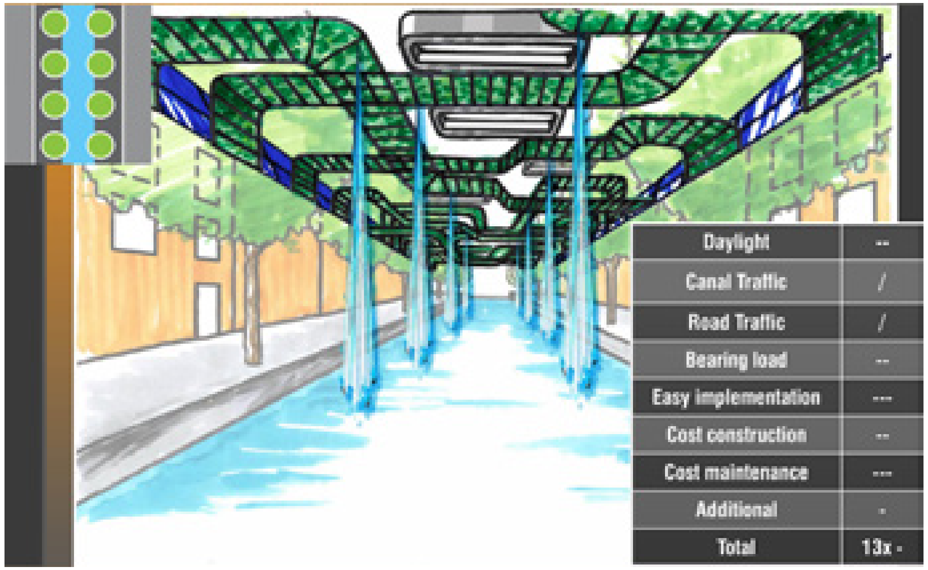


Illustration 104: Feasibility evaluation of Arched Pergola Design of Canal 1-1

- Daylight: in this design, the sunlight is almost fully blocked by the pergolas not only for the canal, but also for the adjacent houses in summer. In winter the climbing plants here should be deciduous and leafless, the influence is then negligible. The "- - -" is for the summer situation.
- Canal Traffic: the canal traffic is slightly influenced by the water falls, but negligible, so the evaluation is "/".
- Road Traffic: in this case road traffic is not influenced, so the evaluation is neutral"/".

- Bearing Load: the arched pergola is large and heavy, which is adding a lot of bearing load onto the houses. The added solar panels are also adding the bearing load. So the evaluation is “- - -”.
- Easy Implementation: the arching pergola is difficult to implement, so the evaluation is “- -”.
- Cost Construction: the arching pergola is expensive, so the evaluation is “- -”.
- Cost Maintenance: The climbing plants of the pergola need to be trimmed regularly. It is hard to repair the fans on the pergola if anything goes wrong. The water falls also need regular maintenance, so the evaluation is “- - -”.
- Additional: the fans and water falls may create constant unpleasant noise, so the evaluation is “- -”.

Puzzle Pergola Design:



Daylight	--
Canal Traffic	/
Road Traffic	/
Bearing load	--
Easy implementation	---
Cost construction	--
Cost maintenance	---
Additional	-
Total	13x -

Illustration 105: Feasibility evaluation of Puzzle Pergola Design of Canal 1-1

- Daylight: in this design the sunlight is largely blocked by the pergolas not only for the canal, but also for the houses in summer. In winter the climbing plants are leafless, the influence is negligible. The “- -” is for the summer.
- Canal Traffic: the canal traffic is slightly influenced by the water sprays, but negligible, so the evaluation is “/”.
- Road Traffic: in this case road traffic is not influenced, so evaluation is neutral “/”.
- Bearing Load: the pergolas and the added solar panels are adding the bearing load of the houses, so the evaluation is “- -”.
- Easy Implementation: the complicated pergolas with bladeless fans are very difficult to implement, so the evaluation is “- - -”.
- Cost Construction: the complicated pergolas with bladeless fans are more expensive than normal ones, so the evaluation is “- -”.
- Cost Maintenance: The climbing plants of the pergolas need to be trimmed regularly. It is hard to repair the bladeless fans on the pergolas if anything goes wrong. The water sprays also need regular maintenance, so the evaluation is “- - -”.
- Additional: the water sprays may create constant unpleasant noise, so the evaluation is “-”.

Water Tank Pergola Design:

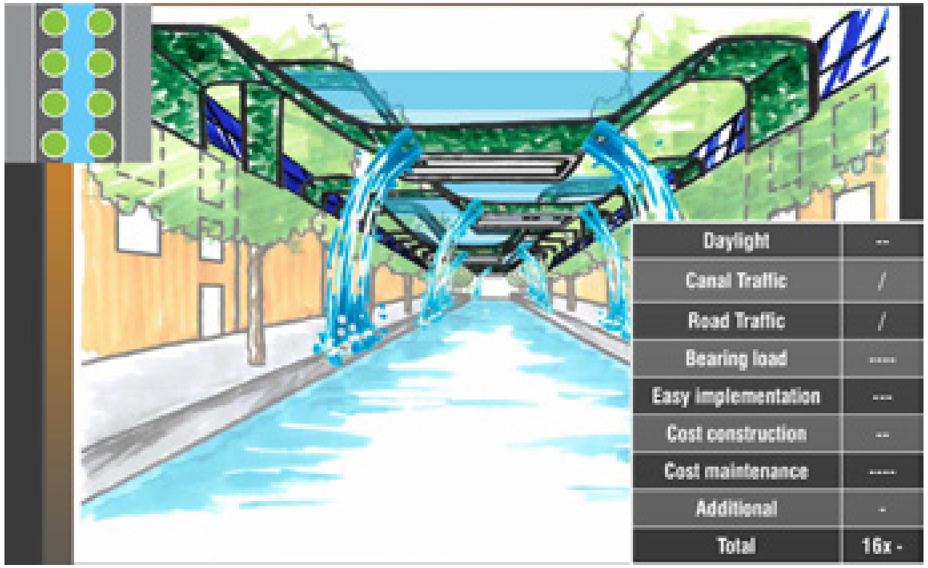


Illustration 106: Feasibility evaluation of Puzzle Pergola Design of Canal 1-1

- Daylight: in this design the sunlight is largely blocked by the pergola not only for the canal, but also for the buildings in summer; In winter the climber is leafless, the influence is negligible. The“- -” is for the summer.
- Canal Traffic: the canal traffic is slightly influenced by the water falls, but negligible, so the evaluation is “/”.
- Road Traffic: in this case road traffic is not influenced, so the evaluation is neutral “/”.
- Bearing Load: the water tanks are very heavy, which add a lot of bearing load. The pergolas and the added solar panels are also adding the bearing load of the houses. So the evaluation is “- - - -”.
- Easy Implementation: the complicated pergolas with bladeless fans and water tanks are very difficult to implement, so the evaluation is “- - -”.
- Cost Construction: the complicated pergolas with water tanks and bladeless fans are more expensive than normal ones, so the evaluation is “- -”.
- Cost Maintenance: The climbing plants of the pergolas needs to be trimmed regularly. It is hard to repair the bladeless fans on the pergolas if anything goes wrong. The water falls and water tanks also need regular maintenance. So the evaluation is “- - - -”.
- Additional: the water falls may create constant unpleasant noise, so the evaluation is “-”.

Web Pergola Design:

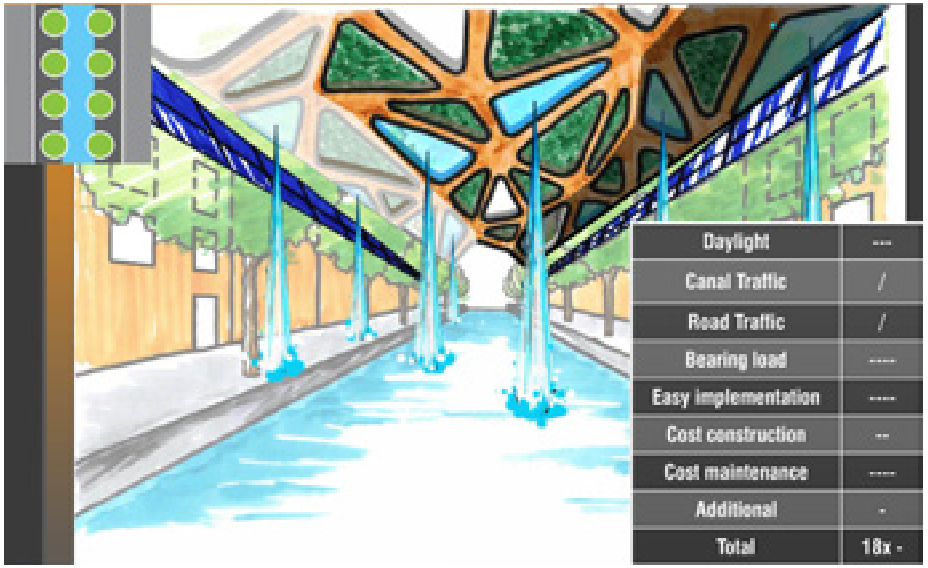


Illustration 107: Feasibility evaluation of Web Pergola Design of Canal 1-1

- Daylight: in this design the sunlight is almost all blocked by the pergola not only for the canal, but also for the buildings in summer; In winter the plant is leafless, the influence is negligible. The “- - -” is for the summer.
- Canal Traffic: the canal traffic is slightly influenced by the water sprays, but negligible, so the evaluation is “/”.
- Road Traffic: in this case road traffic is not influenced, so it’s neutral“/”.
- Bearing Load: the arching pergola with water tanks is large and heavy, which add lots of bearing load to houses. The added solar panels are also

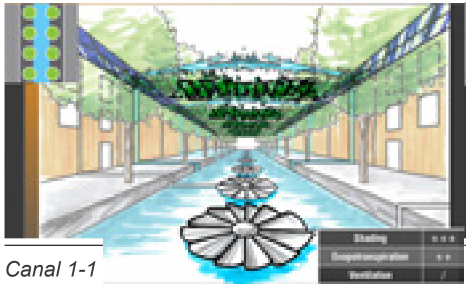
adding the bearing load, so the evaluation is “- - - -”.

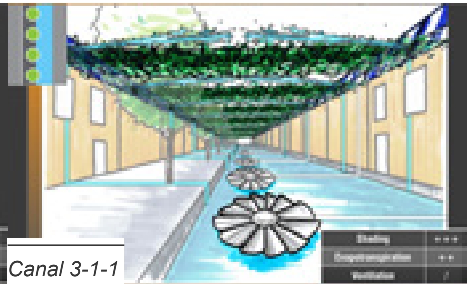
- Easy Implementation: the arching pergola with bladeless fans and water tanks is very difficult to implement, so the evaluation is “- - - -”.
- Cost Construction: the arching pergola with bladeless fans and water tanks is expensive to construct, so the evaluation is “- -”.
- Cost Maintenance: The plants of the pergola needs to be trimmed regularly. It is hard to repair the bladeless fans on the pergola if anything goes wrong. The water sprays and the water tanks also need regular maintenance. So the evaluation is “- - - -”.
- Additional: water sprays may create constant unpleasant noise, so the evaluation is “-”.

Unlike the cooling effect evaluation is for testing, the Feasibility Design Criteria are evaluated for the designs that are not concerned about feasibility. Additively Integrated Designs are focused on cooling effect. Free-style Form Designs are focused on form giving. So, the feasibility evaluations expose the short comings of these designs on feasibility.

6.5 Loop 4 Final Designs and Principles

As it was stated in Additively Integrated Designs, Canal 3-1-1 and 3-2-1's Additively Integrated Designs are similar to Canal 1-1's (Illustration 108). As also Canal 3-2-2's is similar to Canal 3-1-2's (Illustration 111). According to that conclusion, Final Design Principles would be based on Additively Integrated Designs of test-beds: Canal 1-1, 1-2, 2-1, 2-2, and 3-1-2, to show different solutions for very different situations.





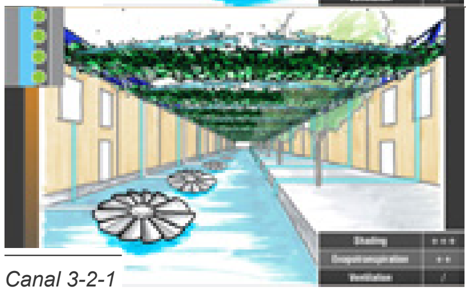


Illustration 108: The series of Additively Integrated Designs of Canal 1-1, 3-1-1, 3-2-1

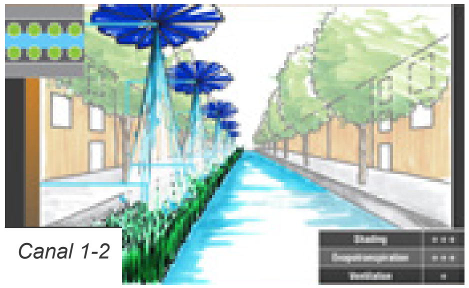
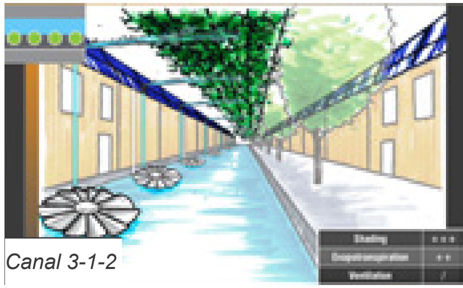


Illustration 109: The Additively Integrated Designs of Canal 1-2

The Free-style Form Design: Arched Pergola Design's form is combined with the Additively Integrated Designs of test-beds: Canal 1-1, 1-2, 3-1-1, 3-1-2, in the because the form is not applicable on the ones of Canal 2-1 and 2-2. The reason that it is not applicable is, Additively Integrated Designs of Canal 2-1, 2-2 are without pergolas or fans.

Illustration 110: The Additively Integrated Designs of Canal 2-1, 2-2



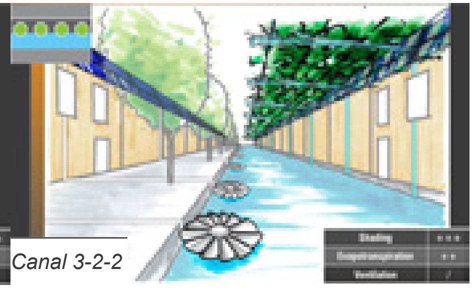


Illustration 111: The Series of Additively Integrated Designs of Canal 3-1-2, 3-2-2

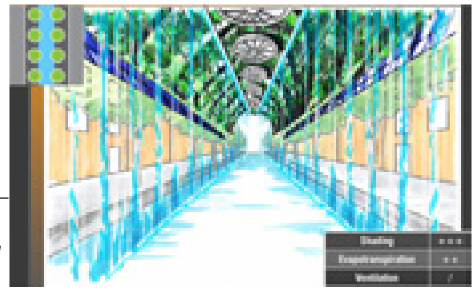


Illustration 112: The Arched Pergola Design of Canal 1-1


llitonkade
Street View - Jun 2015
Billitonkade
LANTSOEN
Lombok
LOMBOK-WEST
Leidseweg
Google
Image capture: Jun 2015
© 2015 Google
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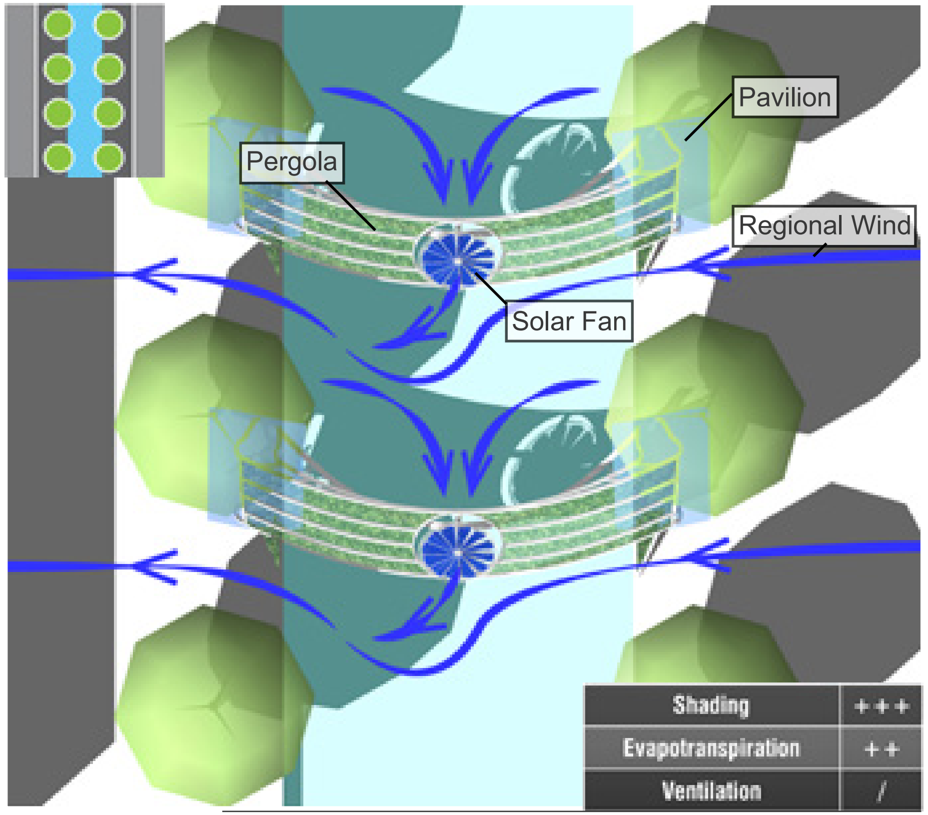
6.5.1 Final Design & Principles of Canal 1-1

Taken Additively Integrated Design and Arched Pergola Design for Canal 1-1, and more importantly their evaluations into account, the final design for test-bed Canal 1-1 is made, so are the design principles. According to all the evaluations, it is improved dramatically in terms of the feasibility.

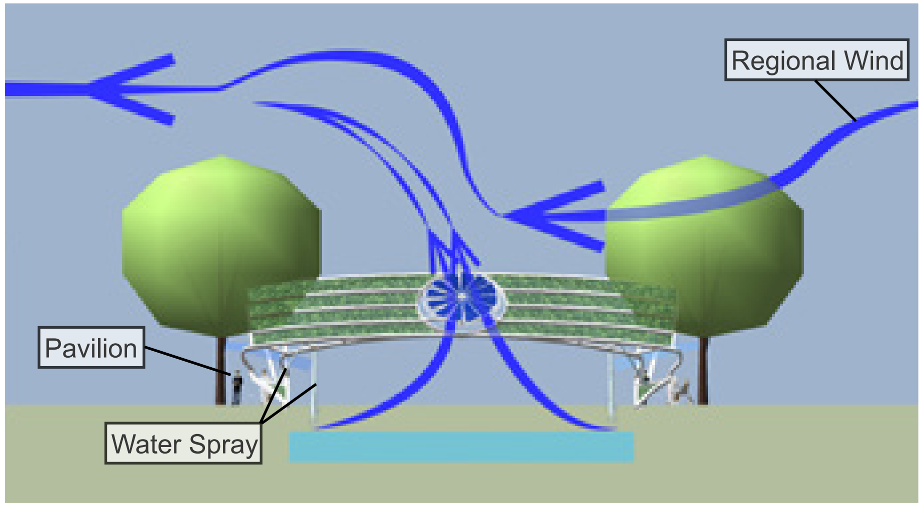
Pergolas are arching over the canal to shade the gaps of the shadows of the trees and tilted to the angle that is perpendicular to the sunlight in hot periods to maximize the shadow area. The climbing plants are deciduous, to let through sunlight in winter. Solar fans are integrated in the middle of the pergolas with the same angle as the pergolas, to receive the max. solar energy. The distance between solar fan and the closest point of the pergola is more than 0.3 m to prevent the climbing plant from growing onto the fan. The pergolas are supported by pavilions. Water sprays are in sun and close to the pavilions, to be close to people. Energy collected by the solar fans is used to power themselves, the water sprays and some charging points for phones in the pavilions.

Cooling effect evaluation results of this design is shown in Illustration 113. Cooling is mainly from the shadows of the pergolas together with the original trees, reflecting and transferring the solar radiation. As the water in the canal and water sprays evaporate, climbing plants and the original trees transpire, the heat is transferred into latent heat in water vapor gathering above the canal. It is drawn up by the solar fans to the regional wind.



Shading	+++
Evapotranspiration	++
Ventilation	/

Illustration 113: Top view of Final Design of Canal 1-1 with shadow & wind



Daylight	/	Bearing load	/	Cost maintenance	---
Canal Traffic	/	Easy implementation	--	Additional	/
Road Traffic	/	Cost construction	---	Total	8x -

Illustration 114: Front view of Final Design of Canal 1-1 with wind

Feasibility of this design is also evaluated (Illustration 114). The pergolas are only covering the canal so that it won't influence houses. Both canal and road traffic are barely influenced. Nothing is attached on the houses, the bearing load is not influenced. Despite that the whole design is in public area, the novel shape of the pergolas and pavilions, and the position of solar fans on the pergolas hanging in the middle above the canal make it hard to implement, so the evaluation of Easy Implementation is "- -". Cost Construction evaluation is "- - -" also because of the novel shapes of pergolas and pavilions, and the invention of solar fans. The regular maintenance of climbing plants, solar fans and water sprays make the Cost Maintenance evaluation "- - -". For Additional evaluation, though fans and water sprays are still creating constant noise, especially to people who are less tolerant to noise, there are other compensating aspects. Both pergolas and solar fans are tilted to the angle that is perpendicular to the sunlight on 1st August, to maximize the received solar energy and the width of the shadow. The solar energy collected is used to run the fans itself and the water sprays, and for charging phones by citizens; the water sprays are designed deliberately very close to the pavilions so that it can be easily approached by people. That is why in feasibility evaluation, the additional aspect is "/", these two "+"s neutralized the two "-"s of the noises.

Final design shows one exemplary solution for Canal 1-1, but not an exclusive one. From the evaluations of it, the design principles of this type can be concluded. Combination of pergola, water spray and solar fan is recommended for Canal 1-1's cooling effect. Pergolas should be arching over the canal to shade the gaps of the shadows of the trees and tilted to the angle that is perpendicular to the sunlight in hot periods. The climbing plants should be deciduous, to let through sunlight in winter. Solar fans should be integrated in the middle of the pergolas with the same angle as the pergolas. The distance between solar fan and the closest point of the pergola should be at least 0.3 m to prevent the climbing plant from growing onto the fan. Water sprays should be positioned in sun and close to canal bank, to be close to people. Energy collected by the solar fans should be used to power themselves, the water sprays and some charging points for phones.

The simulation of how everyday life could happen around the design, can be found in the attached CD.

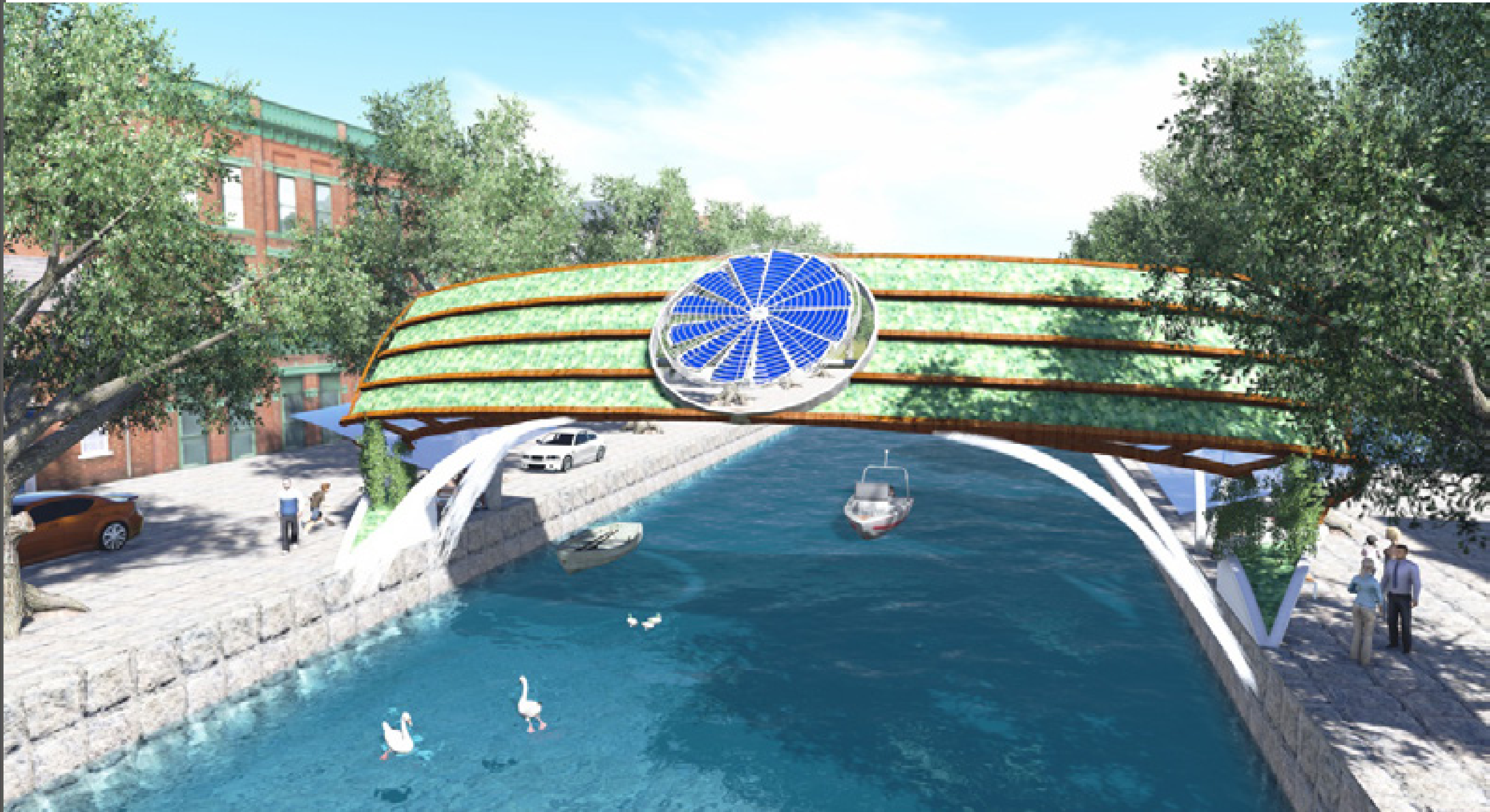


Illustration 115: Bird's View of Final Design of Canal 1-1

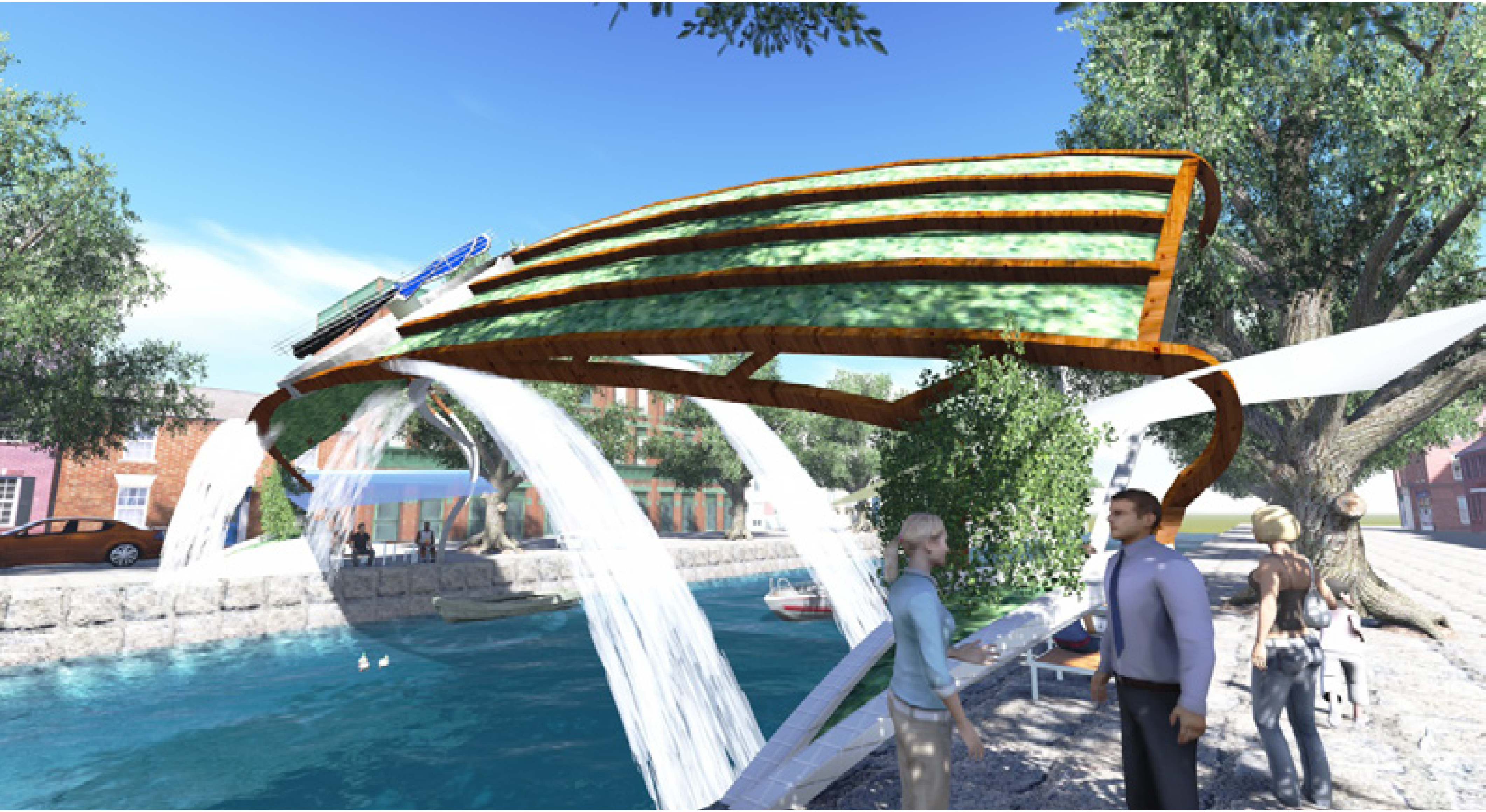


Illustration 116: Human’s View of Final Design of Canal 1-1

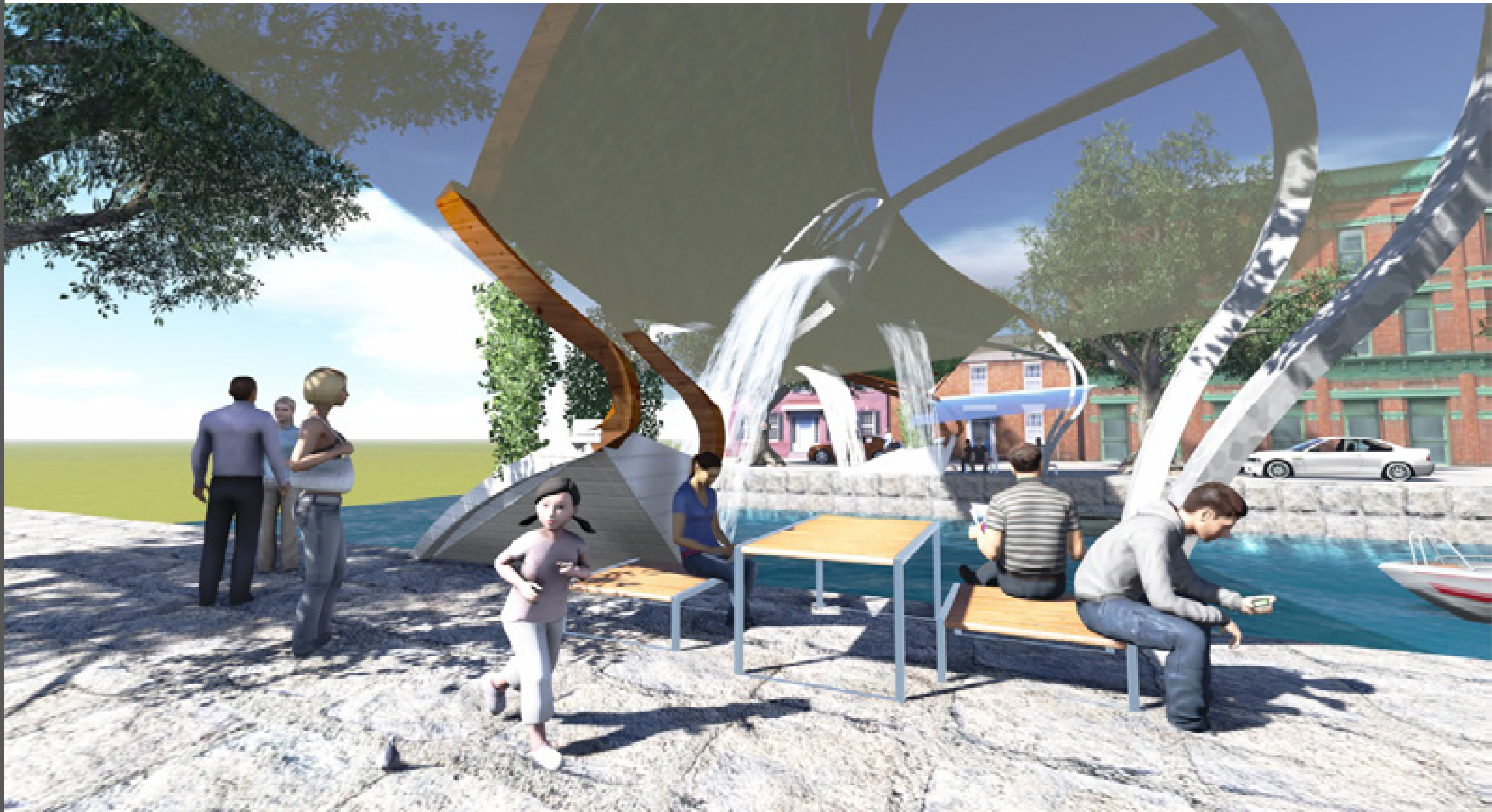


Illustration 117: A pavilion impression of Final Design of Canal 1-1

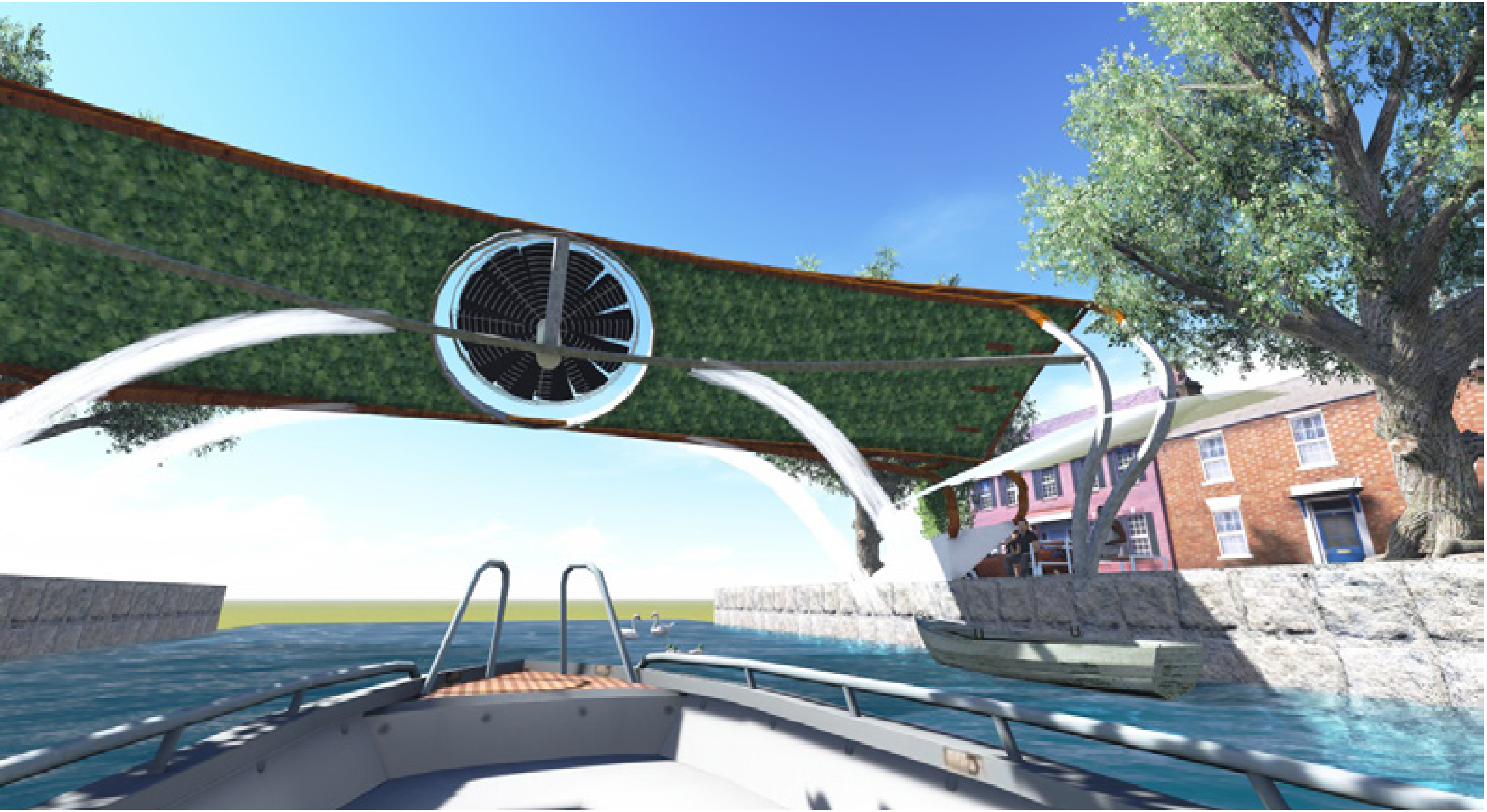


Illustration 118: View from a boat of Final Design of Canal 1-1

Illustration 119: View from a pavilion of Final Design of Canal 1-1

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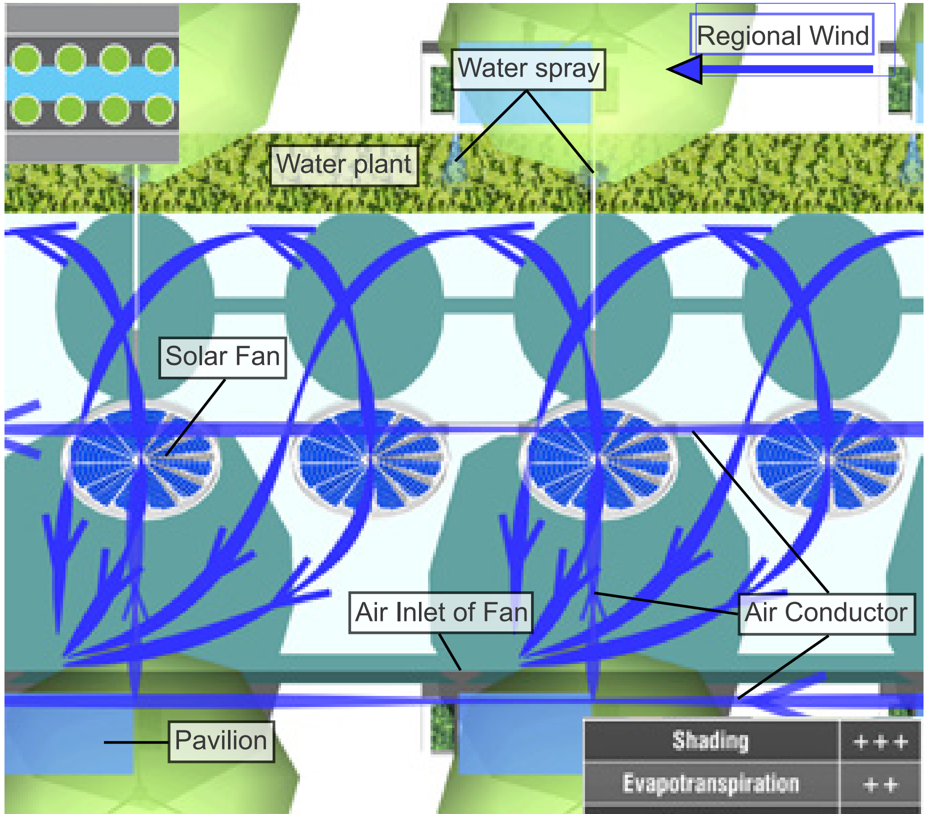
6.5.2 Final Design & Principles of Canal 1-2

This final design is combined from Arched Pergola Design and Additively Integrated Design for Canal 1-2. Solar fans are positioned over the canal to shade the part of the canal that is completely exposed in sun, right northern to the shadows of the trees at noon. They are tilted to the angle that is perpendicular to the sunlight in hot periods, to receive max. solar energy. They are supported by arching structures and pipes conducting air. The air inlets of the fans are positioned on the southern bank of the canal, to be not blocked by water plants.

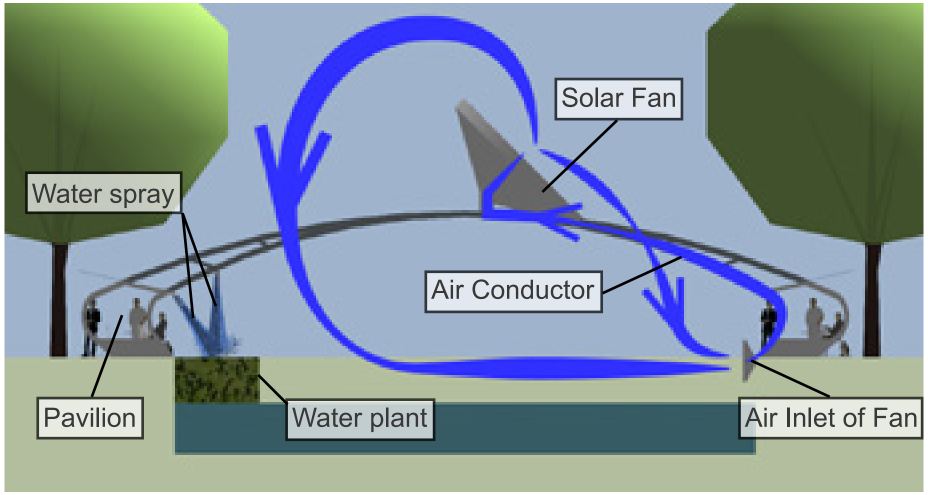


Shading	+++
Evapotranspiration	++
Ventilation	+

Illustration 120: Top view of Final Design of Canal 1-2 with shadow & wind

The bases of the supporting structures are integrated with pavilions with tables and seats. The energy collected by the solar fans is used to power themselves, water sprays and charging points for phones in the pavilions. The water plants are planted on the northern side of the canal to compensate the shading of still unshaded area. The water sprays are installed on the supporting structure above the water plants, exposed in sun, spraying water onto the water plants to maximize the evaporation.

The cooling effect evaluation is in Illustration 120. Shading here is provided by all the water plants, solar fans and the original trees. Water sprays are in the sun and sprayed onto water plants to be more dispersed and evaporate more. Ventilation here basically changes the local wind into two spiral paths. The air is inhaled from the air inlets, and conducted in the pipe illustrated in Illustration 120 and 121. Air is let out at the solar fans. The analysis of the wind seems complicated, but the heat exchanging effect is simple. It creates more convective air circulations and blows away water vapor.



Daylight	/	Bearing load	/	Cost maintenance	---
Canal Traffic	/	Easy implementation	-	Additional	/
Road Traffic	/	Cost construction	--	Total	6x -

Illustration 121: Left view of Final Design of Canal 1-2 with shadow & wind

Feasibility of this design is also evaluated (Illustration 121). The shades of the fans, water plants are only covering the canal so that it won't influence houses. Both canal and road traffic are barely influenced. Nothing is attached on the houses, the bearing load is not influenced. Despite that the whole design is in public area, the position of solar fans on the pergolas hanging in the middle above the canal make it hard to implement, so the evaluation of Easy Implementation is "-". Cost Construction evaluation is "- -" also because of the invention of solar fans. The regular maintenance of climbing plants, solar fans and water sprays makes the Cost Maintenance evaluation "- - -". For Additional evaluation, it is the same as the evaluation of final design of Canal 1-1.

Design principles can be concluded for Canal 1-2, and all the other canals with similar situations that it represents. The combination of water plant, water spray and solar fan is recommended for this type. Solar fans should be positioned over the canal to shade the part of the canal that is completely exposed in sun. They should be tilted to the angle that is perpendicular to the sunlight in hot periods. They shall be supported by arching structures and pipes conducting air. The air inlets of the fans should be positioned on the southern bank of the canal, to be not blocked by water plants. The energy collected by the solar fans should be used to power themselves, water sprays and charging points for phones. The water plants should be planted on the northern side of the canal to compensate the shading of still unshaded area. The water sprays should be installed on the supporting structure above the water plants, exposed in sun, spraying water onto the water plants.

Illustration 122: Bird's view of final design of Canal 1-2

Illustration 123: Human's view of Final Design of Canal 1-2

Illustration 124: A pavilion impression of Final Design of Canal 1-2

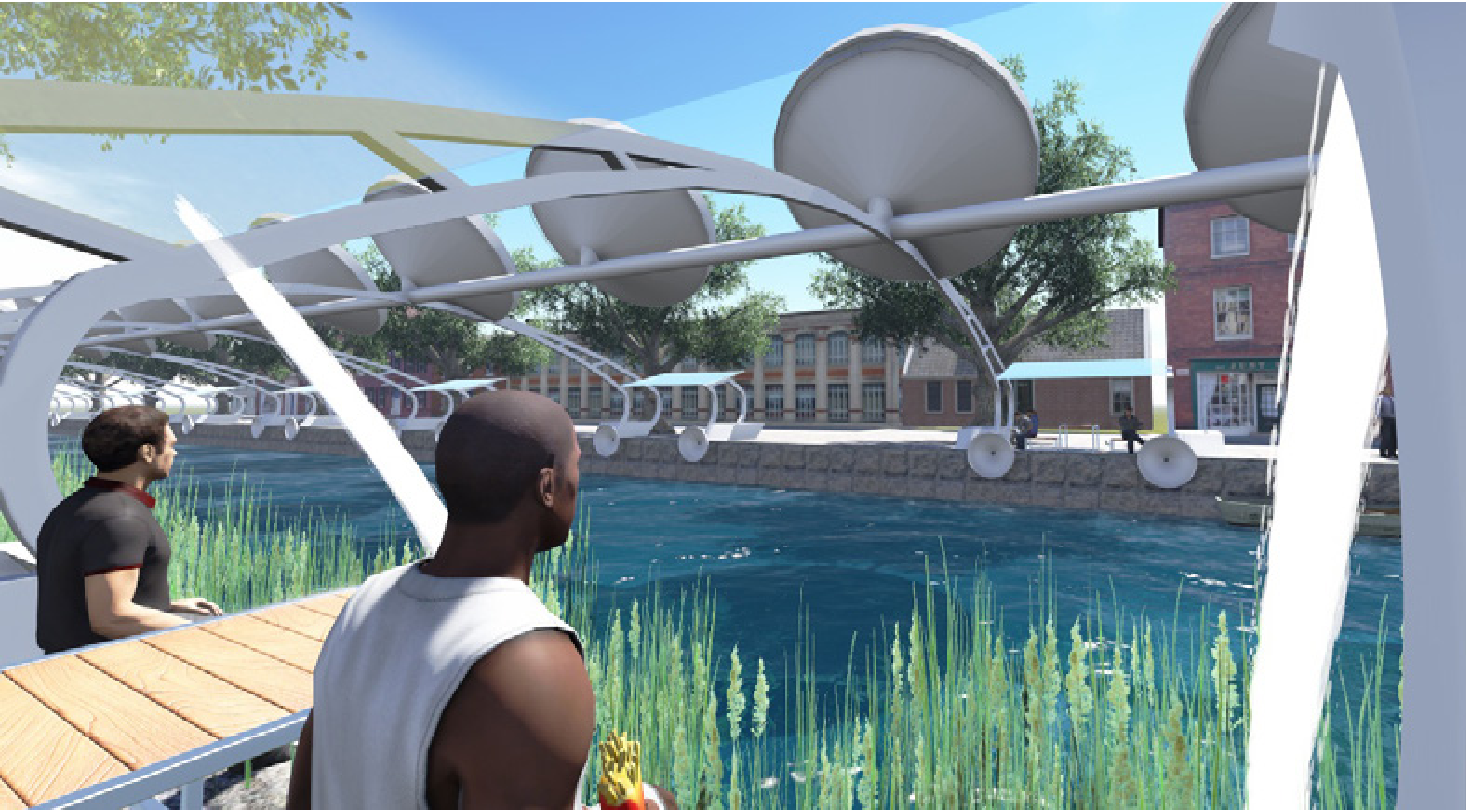


Illustration 125: View from a pavilion of Final Design of Canal 1-2

Illustration 126: View from a boat of Final Design of Canal 1-2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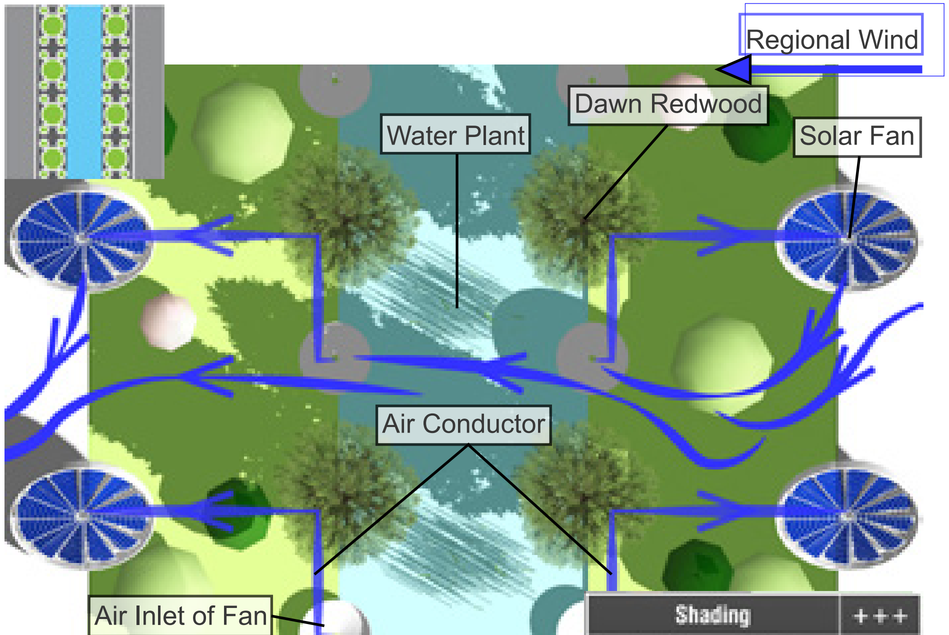
6.5.3 Final Design & Principles of Canal 2-1

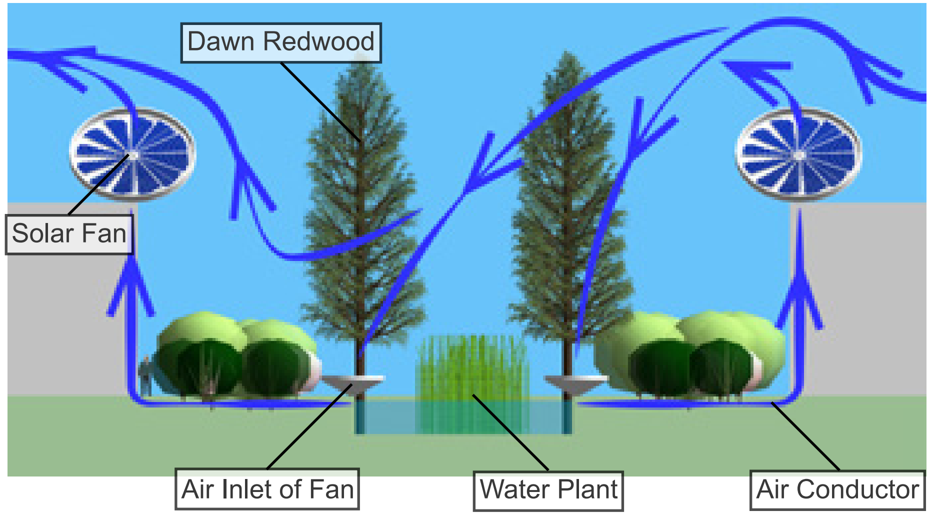
The final design is refined from the Additively Integrated Design for Canal 2-1. Two rows of Dawn Redwoods (mature height 15 meters) are planted symmetrically on both sides of the canal with 10-meter gaps, to shade to most with least trees (like shown in Illustration 127, the gap is just covered by the shades of the tree). Water plants are planted in the middle to compensate the shading of unshaded area. Solar fans are put on the adjacent roofs and tilted to the angle that is perpendicular to the sunlight in hot periods to maximize the collected solar energy. Solar fans' positions on N-S direction are the same as the trees to avoid blocking the wind (as shown in Illustration 127). Air inlets of the fans are put beside the bank in the middle of tree gaps. The energy that is collected by solar fans is not only used to power themselves, the extra part of it is used by the houses adjacent.

The cooling effect here is mainly provided by shading and transpiration from the Dawn Redwoods and water plants. Especially the transpiration of the Dawn Redwoods planted in water is very effective. The ventilation is performed by the solar fans. Here similarly the air is inhaled at the inlets, and conducted out at the fans as shown in Illustration 127, 128.



Shading	+++
Evapotranspiration	+++
Ventilation	+

Illustration 127: Top view of Final Design of Canal 2-1 with shadow & wind



Daylight	-	Bearing load	-	Cost maintenance	---
Canal Traffic	-	Easy implementation	-	Additional	/
Road Traffic	/	Cost construction	---	Total	10x -

Illustration 128: Front view of Final Design of Canal 2-1 with shadow & wind

Feasibility of this design is also evaluated (Illustration 128). The shades of the Dawn Redwoods are covering some of the house windows in spring and summer, so it is “-” for Daylight evaluation. There is no road traffic in this test-bed. But the canal traffic is influenced by the water plants, so the Canal Traffic evaluation is “-”. The solar fans are installed on the roofs of adjacent houses, so the Bearing Load evaluation is “-”. The design is in semi-public area, because the canal is right beside the private back gardens. The Easy Implementation evaluation is then “-”. Cost Construction evaluation is “- - -” because of the invention of solar fans and the high price of Dawn Redwood. The regular maintenance of Dawn Redwoods, solar fans and water plants make the Cost Maintenance evaluation “- - -”. For Additional evaluation, the delight of have a richer landscape over their back gardens and extra energy provided by the solar fans neutralize the nuances of the noise and construction, the “additional” is “/”.

The design principles are concluded from the final design and evaluations for Canal 2-1, and all the other canals with similar situations that it represents. The combination of Dawn Redwood, water plant and solar fan is recommended for this type. Two rows of Dawn Redwoods (mature height 15 meters) should be planted symmetrically on both sides of the canal with 10-meter gaps, to shade to most with least trees. Solar fans should be put on the adjacent roofs and tilted to the angle that is perpendicular to the sunlight in hot periods. Solar fans’ positions on N-S direction should be the same as the trees. Air inlets of the fans should be put beside the bank in the middle of tree gaps. Water plants should be planted in the middle of the canal, southern than the trees but northern than the air inlets to compensate the shading of unshaded area. The energy that is collected by solar fans should be not only used to power themselves, the extra part of it should be used by the houses adjacent.

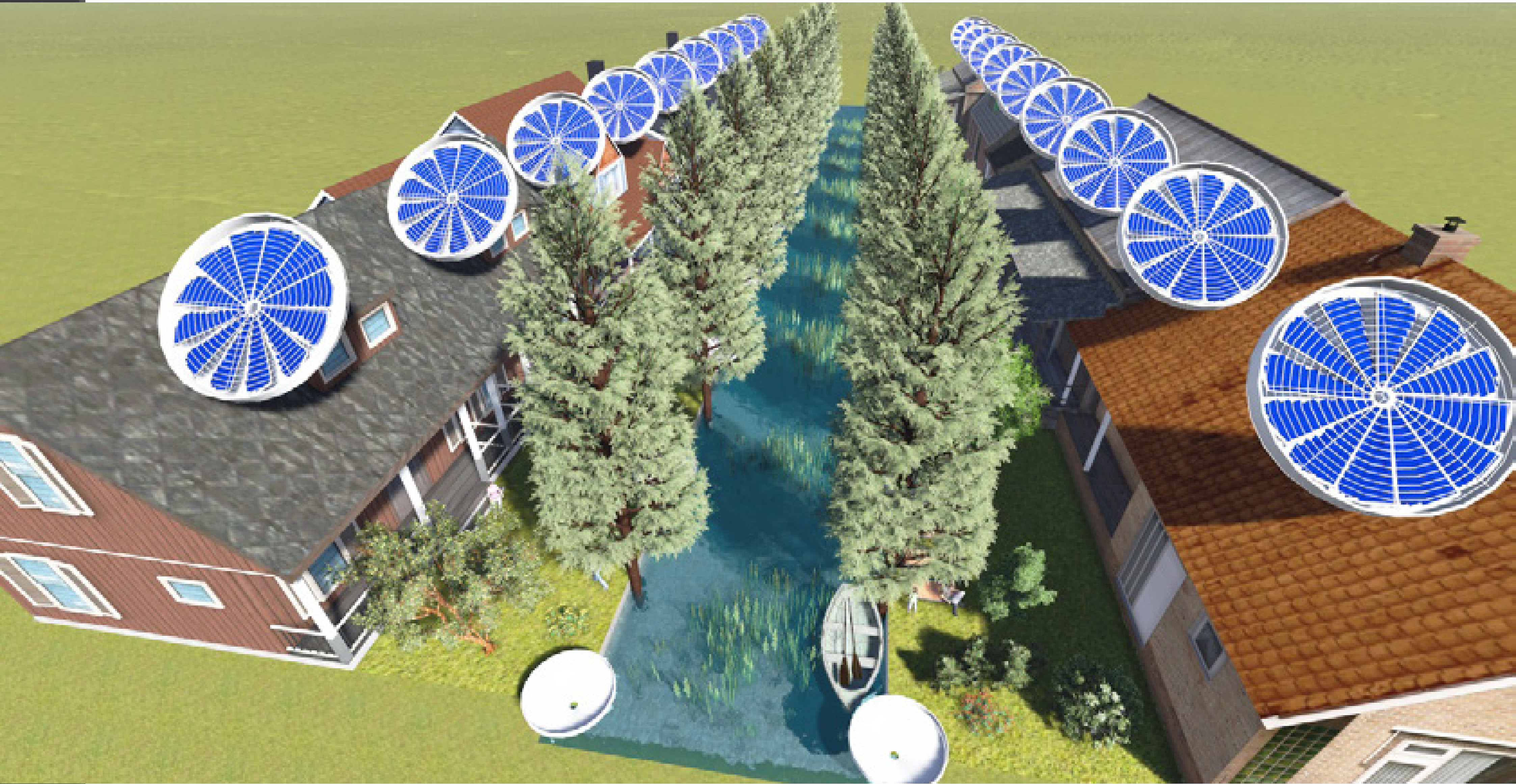


Illustration 129: Bird's view of Final Design of Canal 2-1

Illustration 130: Human's view of Final Design of Canal 2-1

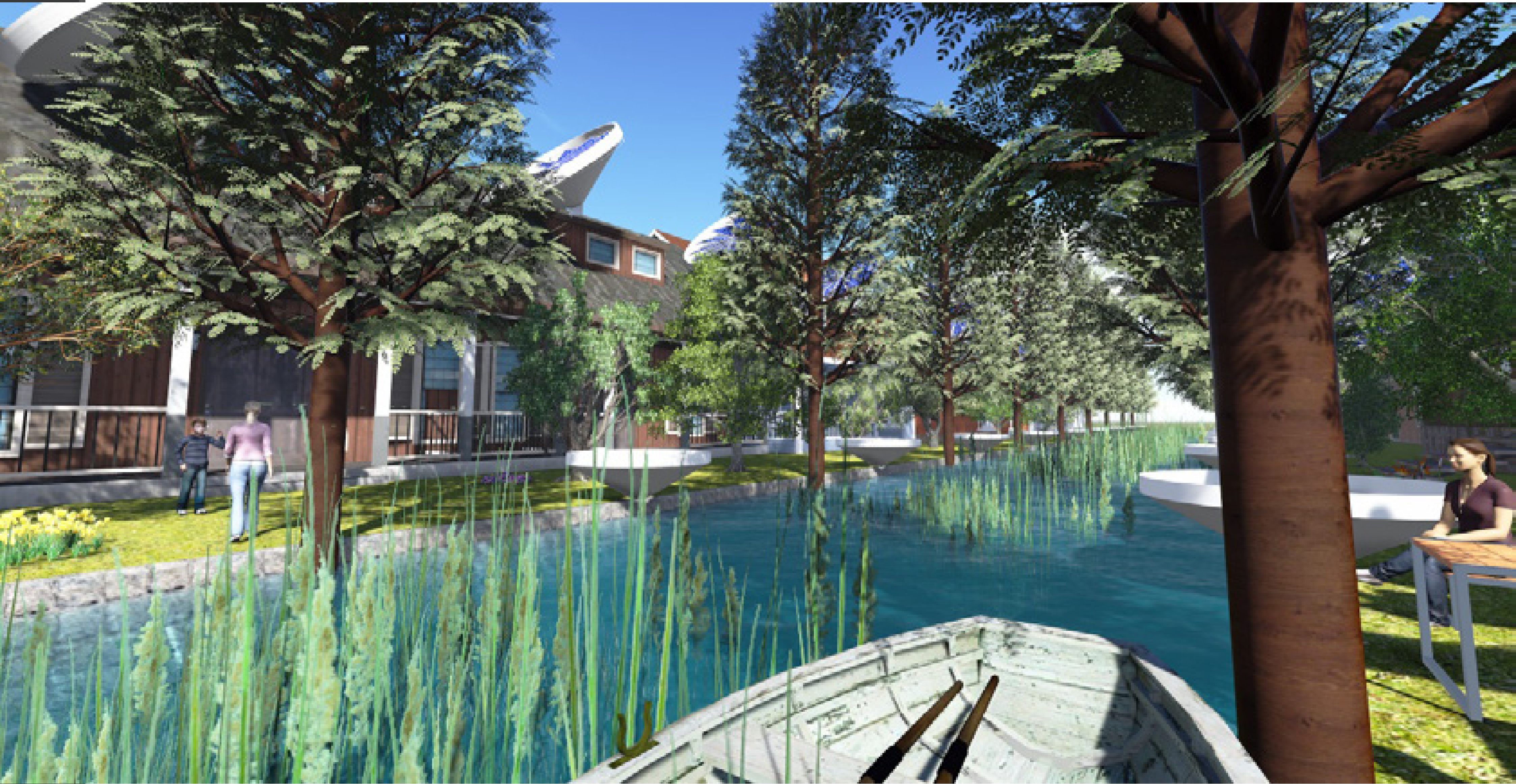


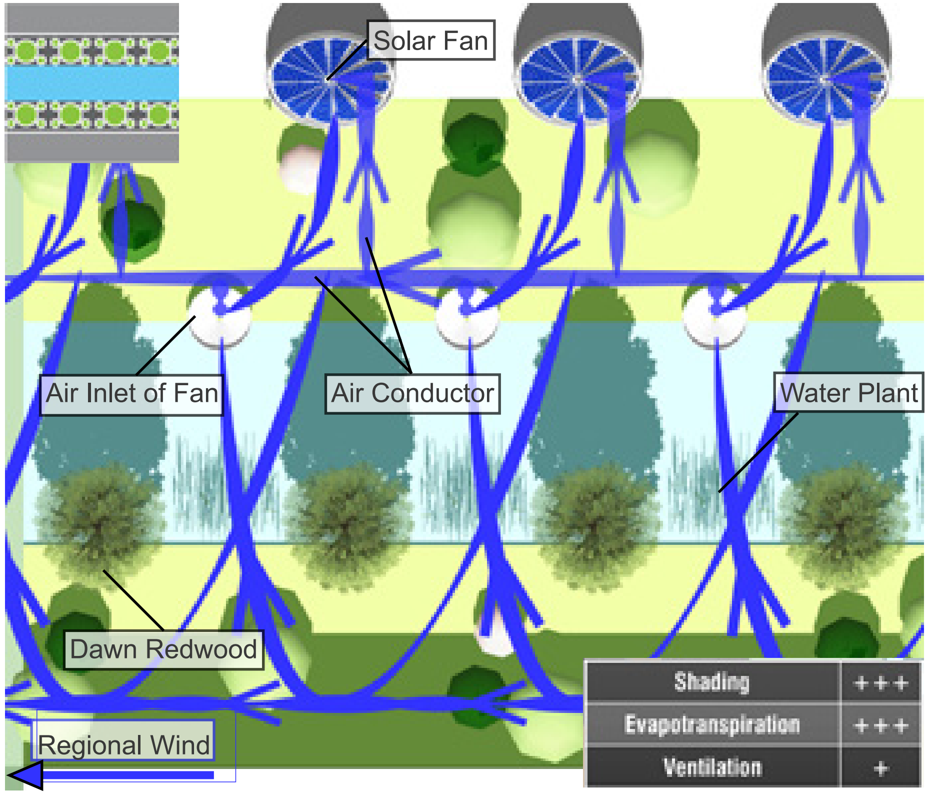
Illustration 131: View from a boat of Final Design of Canal 2-1

Illustration 132: View from a balcony of Final Design of Canal 2-1

6.5.4 Final Design & Principles of Canal 2-2

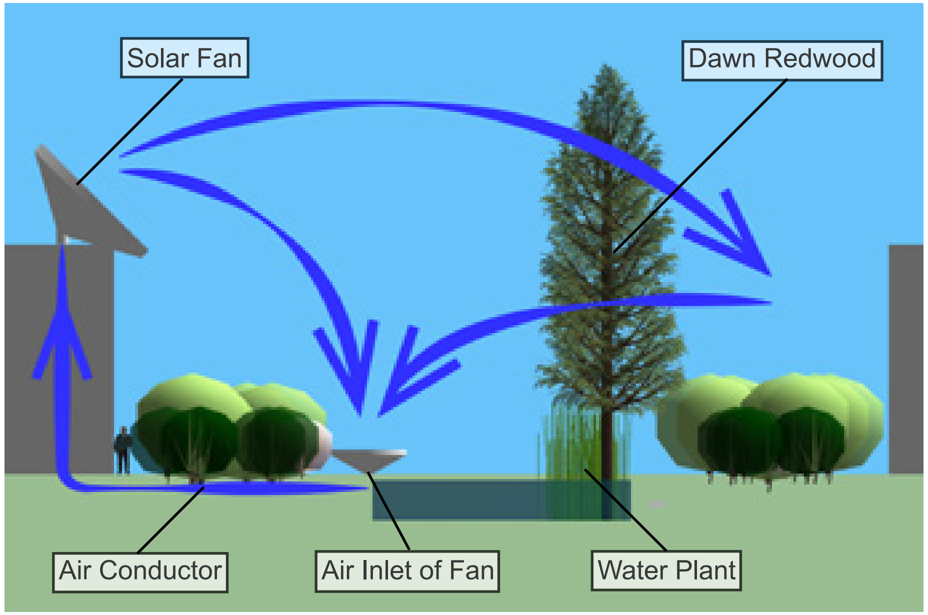
Final design of Canal 2-2 is improved from Additively Integrated Design for Canal 2-2. One row of Dawn Redwoods (mature height 15 meters) are planted on the southern side of the canal with 10-meter gaps, to shade to most with least trees. Water plants are planted in the middle of the gaps to compensate the shading of unshaded area. Solar fans are put on the northern adjacent roofs and tilted to the angle that is perpendicular to the sunlight in hot periods. Solar fans' positions on E-W direction are the same as the trees to be more effective in ventilating the air in the southern part of the canyon (as shown in Illustration 133). Air inlets of the fans are put beside the northern bank to the middle of tree gaps. The energy that is collected by solar fans is not only used to power themselves, the extra part of it is used by the houses adjacent.

Here, the cooling mechanism is similar to the last test-bed. Cooling effect is also mainly provided by shading and transpiration from the Dawn Redwoods and water plants. Especially the transpiration of the Dawn Redwoods planted in water is very effective. The ventilation is performed by the solar fans. Here similarly the air is inhaled at the inlets, and conducted out at the fans as shown in Illustration 133, 134.



Shading	+++
Evapotranspiration	+++
Ventilation	+

Illustration 133: Top view of Final Design of Canal 2-2 with shadow & wind



Daylight	/	Bearing load	-	Cost maintenance	---
Canal Traffic	-	Easy implementation	-	Additional	/
Road Traffic	/	Cost construction	--	Total	8x -

Illustration 134: Left view of Final Design of Canal 2-2 with shadow & wind

Feasibility of this design is also evaluated (Illustration 134). The shades of the Dawn Redwoods are only covering the canal, so it is "-" for Daylight evaluation. There is no road traffic in this test-bed. But the canal traffic is influenced by the water plants, so the Canal Traffic evaluation is "-". The solar fans are installed on the roofs of adjacent houses, so the Bearing Load evaluation is "-". The design is in semi-public area, because the canal is right beside the private back gardens. The Easy Implementation evaluation is then "-". Cost Construction evaluation is "- -" because of the invention of solar fans, and only one row of Dawn Redwoods is less expensive. The regular maintenance of Dawn Redwoods, solar fans and water plants make the Cost Maintenance evaluation "- - -". For Additional evaluation, the delight of have a richer landscape over their back gardens and extra energy provided by the solar fans neutralize the nuances of the noise and construction, the "additional" is "/".

From the final design of Canal 2-2 and its evaluations, design principles can be concluded for Canal 2-2, and all the other canals with similar situations that it represents. The combination of Dawn Redwood, water plant and solar fan is recommended for Canal 2-2. One row of Dawn Redwoods (mature height 15 meters) should be planted on the southern side of the canal with 10-meter gaps, to shade to most with least trees. Water plants should be planted in the middle of the gaps to compensate the shading of unshaded area. Solar fans should be put on the northern adjacent roofs and tilted to the angle that is perpendicular to the sunlight in hot periods. Solar fans' positions on E-W direction should be the same as the trees. Air inlets of the fans should be put beside the northern bank to the middle of tree gaps. The energy that is collected by solar fans should be not only used to power themselves, the extra part of it should also be used by the houses adjacent.

Illustration 135: View from a boat of Final Design of Canal 2-2

Illustration 136: Human's View of Final Design of Canal 2-2

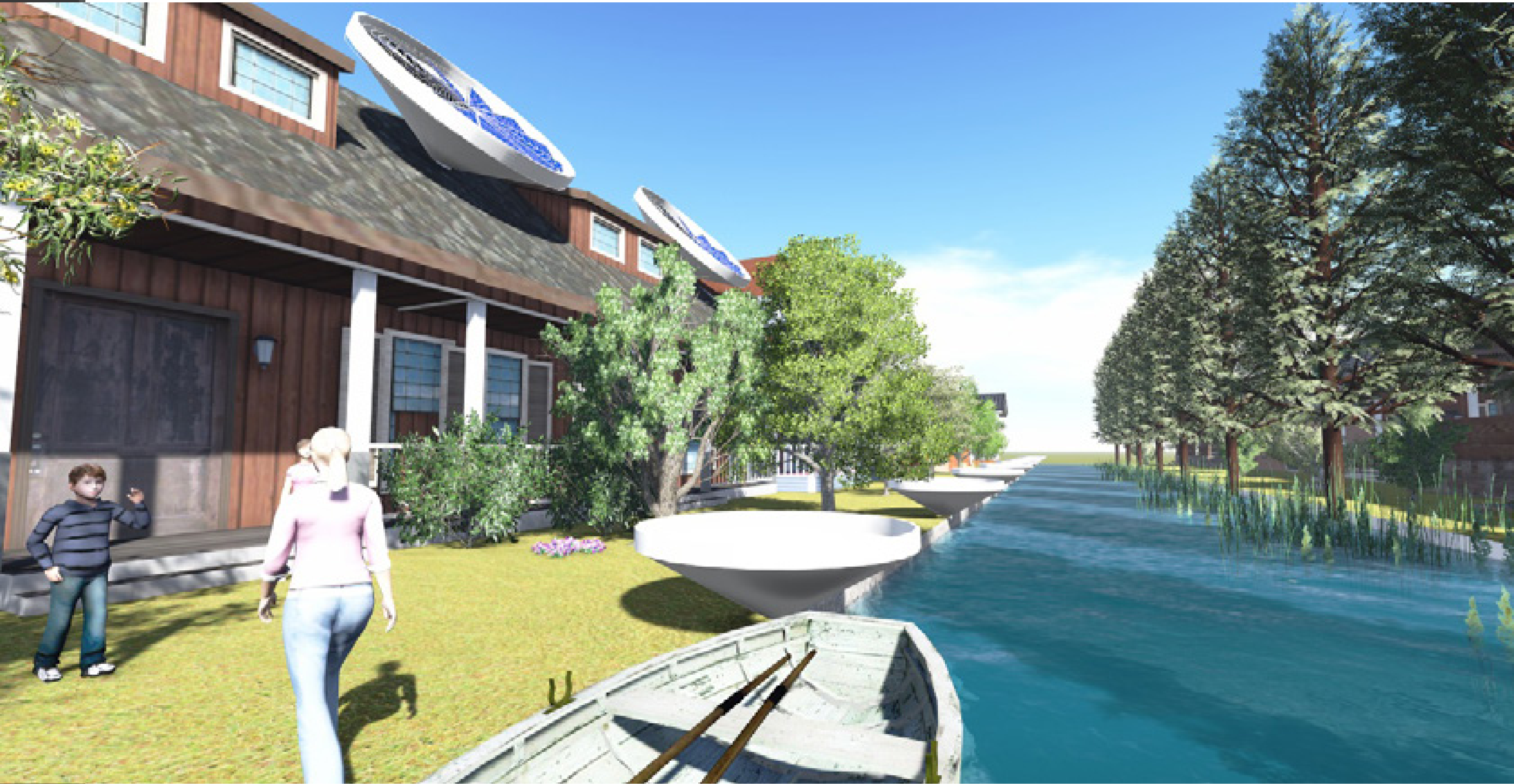


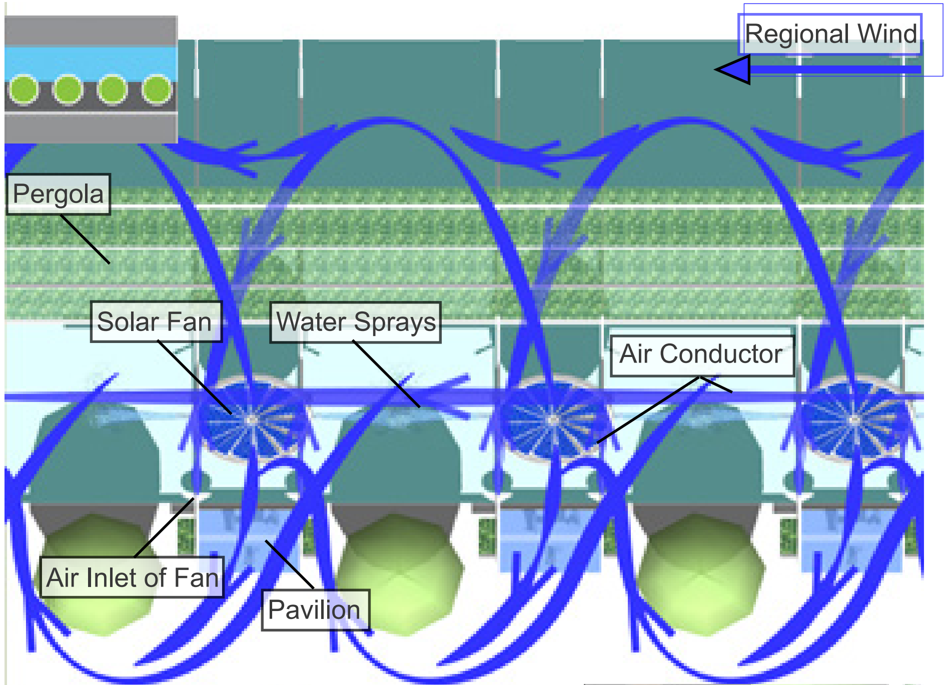
Illustration 137: View from a boat of Final Design of Canal 2-2

Illustration 138: View from a balcony of Final Design of Canal 2-2

6.5.5 Final Design & Principles of Canal 3-1-2

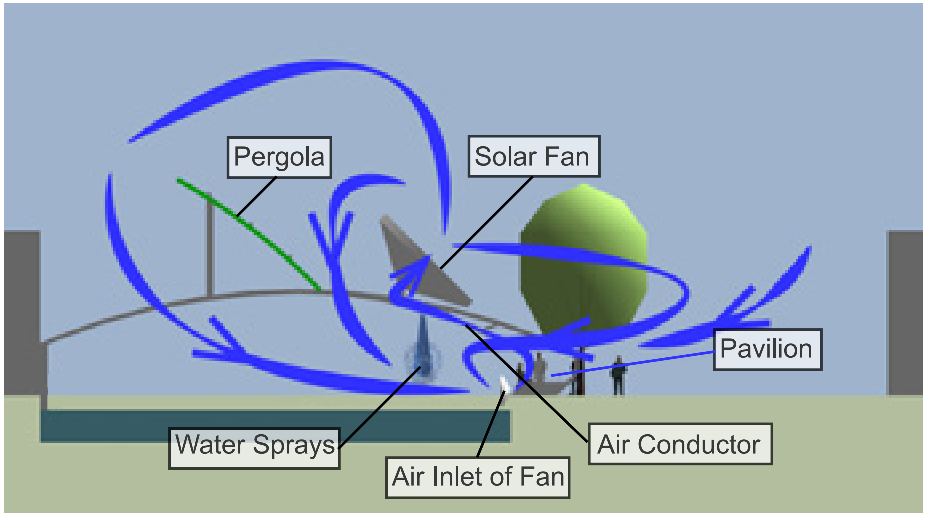
This final design combined from the Arched Pergola Design, and Additively Integrated Design for 3-1-2. The pergola is supported in the middle above the canal by arching structures. It is tilted to the angle that is perpendicular to the sunlight in hot periods, to maximize the shadow. The northern part of the canal is shaded by the pergola. The southern part of the canal is partly shaded by the original trees. Solar fans are installed on the supporting structure of the pergola to shade the gap between the shadows of the pergola and the row of street trees. They are also tilted to the angle that is perpendicular to the sunlight in hot periods to maximize the received energy. Solar fans in the middle of the canyon instead of in the northern side is more effective for ventilation for the whole canyon. The supporting structure's bases on the southern bank is designed into pavilions with tables and seats. The air inlets of the fans are positioned on the side of the canal between the trees. Water sprays are installed on the supporting structure between solar fans. They are exposed in sun.

The cooling effect evaluation of this design is shown in Illustration 139. Shading is provided by pergola and solar fans. Water sprays evaporate quite effectively. Climbing plants on the pergola also transpire a bit. Solar fans ventilate by drawing air through the pipes from the air inlets.



Shading	+++
Evapotranspiration	++
Ventilation	/

Illustration 139: Top view of Final Design of Canal 3-1-2 with shadow & wind



Daylight	/	Bearing load	-	Cost maintenance	---
Canal Traffic	/	Easy implementation	--	Additional	-
Road Traffic	/	Cost construction	---	Total	10x -

Illustration 140: Left view of Final Design of Canal 3-1-2 with shadow & wind

Feasibility of this design is also evaluated (Illustration 140). The pergolas are only covering the canal so that it won't influence houses. Both canal and road traffic are barely influenced. The pergola's supporting structure is partly leaning on the houses, so the Bearing Load evaluation is "-". Despite that the whole design is in public area, the novel shapes of the pergolas and pavilions, and the position of solar fans on the pergolas hanging in the middle above the canal make it hard to implement, so the evaluation of Easy Implementation is "- -". Cost Construction evaluation is "- - -" also because of the novel shapes of pergolas and pavilions, and the invention of solar fans. The regular maintenance of climbing plants, solar fans and water sprays makes the Cost Maintenance evaluation "- - -". For Additional evaluation, here to ensure the evaporation, the water sprays are put in sun but not close to people. The efficiently collected energy by the solar fans neutralized one "-" of the two "- -" of the noise produced by both fans and water sprays. So the Additional evaluation is "-".

The design principles can be concluded for Canal 3-1-2, and all the other canals with similar situations that it represents. The combination of pergola, water spray and solar fan is recommended for it. The pergola should be supported in the middle above the canal. It should be tilted to the angle that is perpendicular to the sunlight in hot periods, to maximize the shadow. The northern part of the canal is then shaded by the pergola. Solar fans should be installed on the supporting structure of the pergola to shade the gap between the shadows of the pergola and the row of street trees. They should also be tilted to the angle that is perpendicular to the sunlight in hot periods. The air inlets of the fans should be positioned on the side of the canal between the trees. Water sprays should be installed on the supporting structure between solar fans.

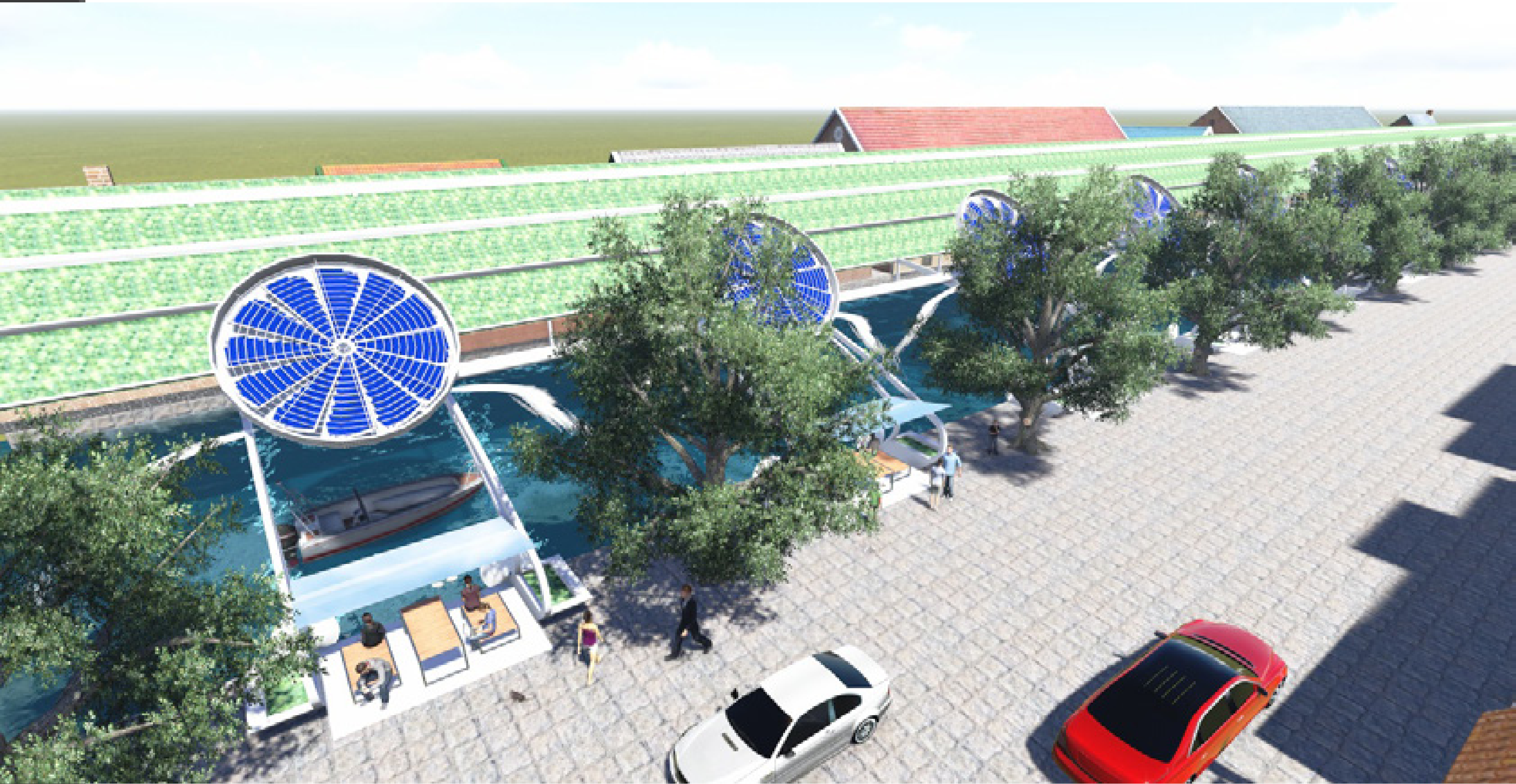


Illustration 141: Bird's view of Final Design of Canal 3-1-2

Illustration 142: Human's view of Final Design of Canal 3-1-2

Illustration 143: A pavilion impression of Final Design of Canal 3-1-2

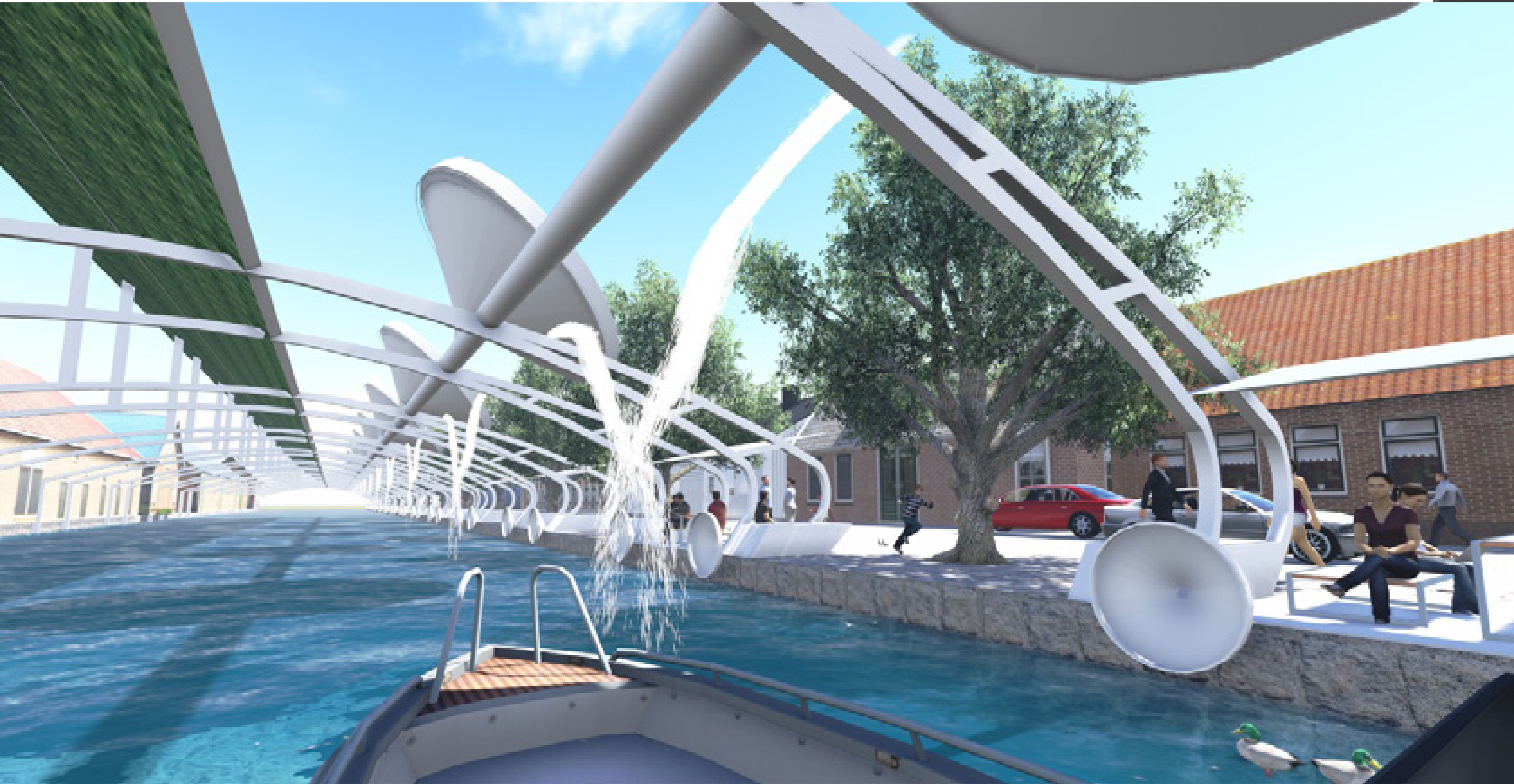


Illustration 144: View from a boat of Final Design of Canal 3-1-2

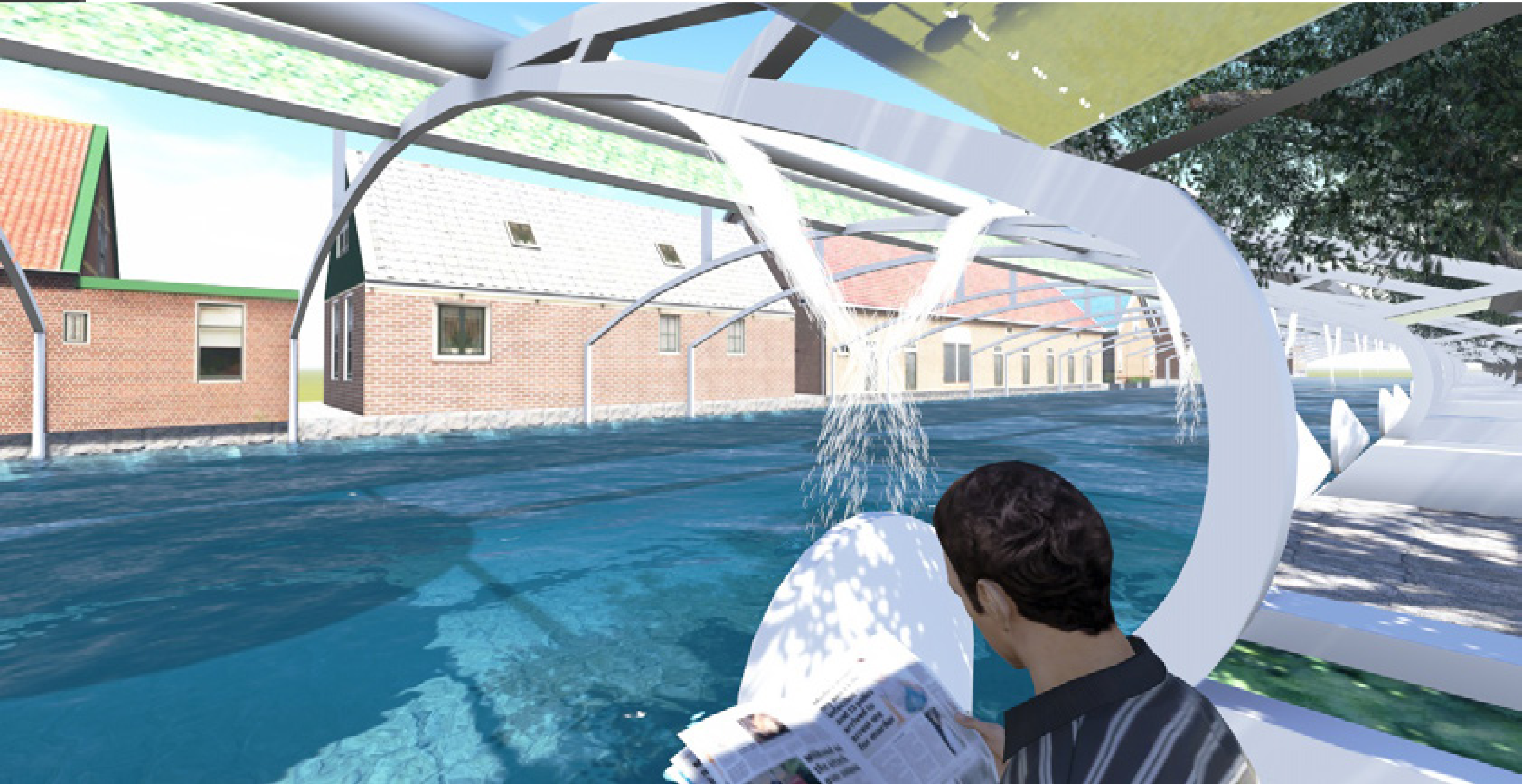


Illustration 145: View from a pavilion of Final Design of Canal 3-1-2

Chapter 7 Conclusion

7 Conclusion

7.1 Summary

In this research it is shown how to systematically identify typical water bodies in terms of heat-stress mitigation, and tested the methodology in the residential areas of city Utrecht, which answered the first sub-research question, and can be tested in further and larger scope.

In the Cooling Effect Design Criteria Identification Chapter, and Design Loops Chapter, different sets of criteria of different aspects are identified and refined, to guide and evaluate the designs of heat-stress mitigation of urban water bodies, including cooling effect evaluation criteria and feasibility evaluation criteria, which answered the second sub-research question, and can be valid for further study in the same field.

The preparation and the RTD process are the research-design process that leads to the truly cooling water body design principles of the urban water bodies in the research area, which answers the third sub-research question. It can be also applied and refined in further research of truly cooling water body.

In the end, different final designs and principles for representative test-beds are concluded, which answered the main research question, and can be prototypes for further urban water bodies designs for heat-stress mitigation.

7.2 Answers of Research Questions

With the final results, the answers of the research questions can be articulated. The answers to the sub-research questions are:

- ***What are relevant types of water bodies in high heat-stress residential areas?***

In my research area, the relevant types of water bodies are the canal types that are identified in Test-bed Identification Chapter (Illustration 146). In other research areas other than Utrecht, the process of identification is still relevant.

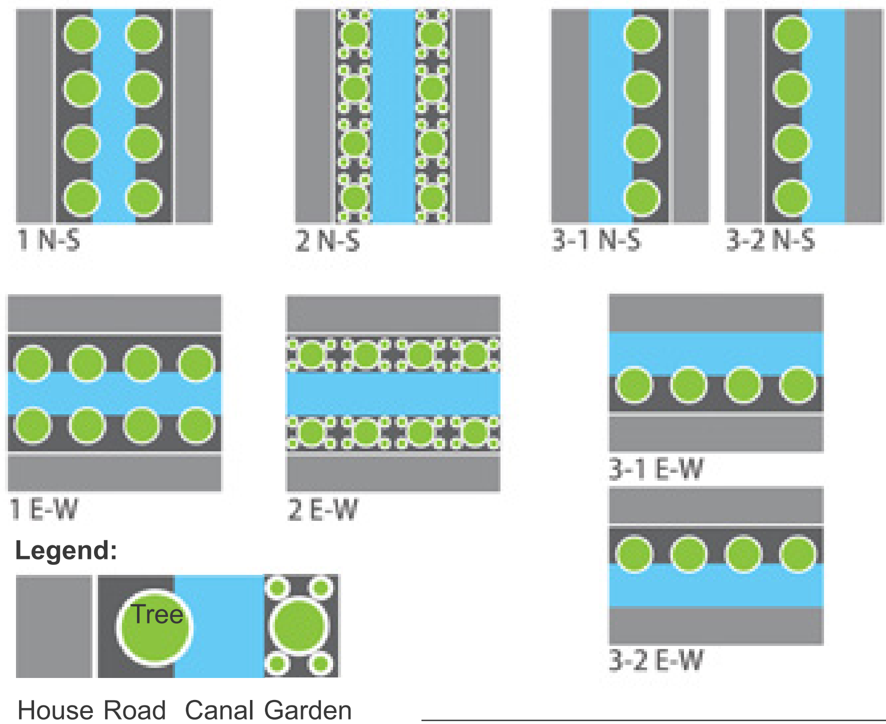


Illustration 146: Profiles of final identified test-beds

The map of high heat-stress areas and residential areas should be overlaid, and the water bodies in intersections of the two kinds of areas are relevant to truly cooling water body design. The categorisation of the water bodies under the criteria of their characteristics including their profiles, orientations, scales, etc. leads to the relevant water body types for truly cooling water body design.

- ***Under what criteria can these types of water bodies be designed to become truly cooling water bodies?***

In the Cooling Effect Design Criteria Chapter and Design Loops Chapter, the criteria of cooling effect and feasibility are already articulated. For cooling effect, the criteria are organized under the three cooling mechanisms concluded from the literature: shading, evapotranspiration and ventilation. For shading mechanism, the shading interventions should be shading the areas of the water body that is fully expose in sun. For evapotranspiration mechanism, the evapotranspiration interventions should be exposed in sun as much as possible near the canal, ideally also be near the ventilation. For ventilation,, the ventilation, it should be through the evapotranspiration interventions to be able to efficiently blow away the water vapor. And the ventilation interventions should not be against the wind, should be able to be integrated with the regional wind.

For the feasibility, eight factors are taken into account: daylight, canal traffic, road traffic, bearing load, easy implementation, cost of construction, cost of maintenance and additional. Daylight intrusion in houses is very crucial to the everyday life of residence living around the canal. The cooling interventions shall block as less sunlight for the adjacent house as possible. Canal traffic, space for small vessels to travel is necessary for the canals. As observed, people enjoy recreational canoeing in the canals. Road traffic, space for traffic and parking is important. As observed, usually space beside the canals is used as parking lots if there are roads beside the canal. Bearing load of the houses should be taken into account if the cooling interventions are attached onto the house adjacent. As observed, the house in Utrecht are usually old house with not much capacity of extra bearing load. Easy implementation, whether the interventions are in public or private space is vital for implementation. If it is in private space, it is quite hard to convince the house holders. Also if it is in place where it is hard to implement interventions, like in the middle of a canal, it is less feasible. The cost of the construction, budget of the interventions is sure limited, the lower the cost, the more the feasibility. The same goes to the maintenance cost. Energy sustaining and even extra energy providing make it cheaper to maintain. Additionally, other environmental, and recreational considerations, like preventing the noise, providing the picturesque view, providing the approach of water, providing phone charging facilities, etc.

- ***In what research-design process can truly cooling water body design principles be generated?***

In this research, the RTD main stage shown in Illustration 147 has led to the truly cooling water body design principles in the research area. Similar process can also be applied to other high heat-stress areas with different kinds of urban water bodies. In that way, more truly cooling water body design principles for more water body types can be generated.

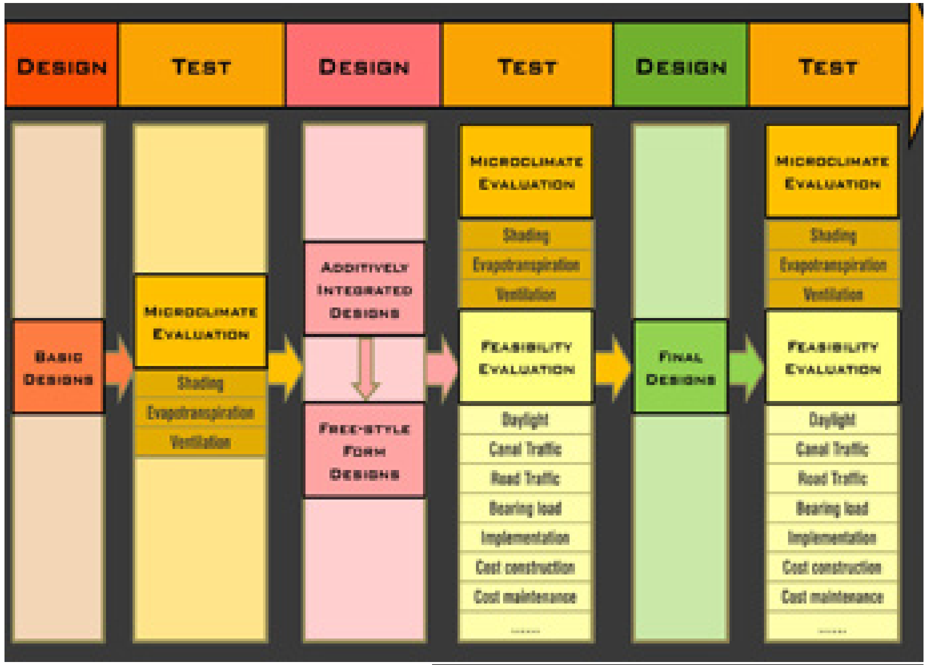
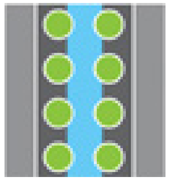


Illustration 147: The RTD main stage - design loops

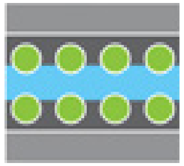
As the sub-research questions are answered, the main research question is also answered. The main research question is:

- ***What design types can truly cool water bodies in residential areas to mitigate urban heat-stress?***

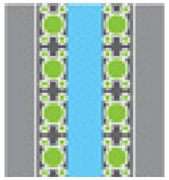
The final sub chapter: LOOP 4 Final Design Principles answers this question at length by illustrating the final designs and concluding the design principles for each representative water body in the research area.



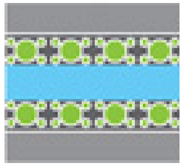
Combination of pergola, water spray and solar fan is recommended for type Canal 1-1. Pergolas should be arching over the canal to shade the gaps of the shadows of the trees and tilted to the angle that is perpendicular to the sunlight in hot periods. The climbing plants should be deciduous, to let through sunlight in winter. Solar fans should be integrated in the middle of the pergolas with the same angle as the pergolas. The distance between solar fan and the closest point of the pergola should be at least 0.3 m to prevent the climbing plant from growing onto the fan. Water sprays should be positioned in sun and close to canal bank, to be close to people. Energy collected by the solar fans should be used to power themselves, the water sprays and some charging points for phones.



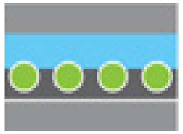
The combination of water plant, water spray and solar fan is recommended for Canal 1-2 type. Solar fans should be positioned over the canal to shade the part of the canal that is completely exposed in sun. They should be tilted to the angle that is perpendicular to the sunlight in hot periods. They shall be supported by arching structures and pipes conducting air. The air inlets of the fans are positioned on the southern bank of the canal, to be not blocked by water plants. The energy collected by the solar fans should be used to power themselves, water sprays and charging points for phones. The water plants should be planted on the northern side of the canal to compensate the shading of still unshaded area. The water sprays should be installed on the supporting structure above the water plants, exposed in sun, spraying water onto the water plants.



The combination of Dawn Redwood, water plant and solar fan is recommended for Canal 2-1 type. Two rows of Dawn Redwoods (mature height 15 meters) should be planted symmetrically on both sides of the canal with 10-meter gaps, to shade to most with least trees. Solar fans should be put on the adjacent roofs and tilted to the angle that is perpendicular to the sunlight in hot periods. Solar fans' positions on N-S direction should be the same as the trees. Air inlets of the fans should be put beside the bank in the middle of tree gaps. Water plants should be planted in the middle southern than the trees but northern than the air inlets to compensate the shading of unshaded area. The energy that is collected by solar fans should be not only used to power themselves, the extra part of it should be used by the houses adjacent.



The combination of Dawn Redwood, water plant and solar fan is recommended for Canal 2-2 type. One row of Dawn Redwoods (mature height 15 meters) should be planted on the southern side of the canal with 10-meter gaps, to shade to most with least trees. Water plants should be planted in the middle of the gaps to compensate the shading of unshaded area. Solar fans should be put on the northern adjacent roofs and tilted to the angle that is perpendicular to the sunlight in hot periods. Solar fans' positions on E-W direction should be the same as the trees. Air inlets of the fans should be put beside the northern bank to the middle of tree gaps. The energy that is collected by solar fans should be not only used to power themselves, the extra part of it should also be used by the houses adjacent.



The combination of pergola, water spray and solar fan is recommended for Canal 3-1-2 type. The pergola should be supported in the middle above the canal. It should be tilted to the angle that is perpendicular to the sunlight in hot periods, to maximize the shadow. The northern part of the canal is then shaded by the pergola. Solar fans should be installed on the supporting structure of the pergola to shade the gap between the shadows of the pergola and the row of street trees. They should also be tilted to the angle that is perpendicular to the sunlight in hot periods. The air inlets of the fans should be positioned on the side of the canal between the trees. Water sprays should be installed on the supporting structure between solar fans.

7.3 Reflection

7.3.1 The RTD Process

In the RTD process, this research put much value and focus on the urban heat-stress mitigation, and pushed the cooling effect to an extent, which makes the final design principles appear to be over-cooling for current climate, however, completely appropriate for the adaptation of the future climate. It has to do with the particular RTD process I chose. I chose to only focus on the cooling effect at the beginning, then later to make them feasible after the Additively Integrated Design Loop, but still maintain the cooling effect. I chose this process because this thesis is focused on the cooling effect of water bodies. If I consider the cooling effect and the feasibility together from the beginning, the methods of cooling I used would not be so explorative and effective in terms of cooling. It has to do with the thinking pattern that our brains unconsciously choose different approaches for different situations. This phenomenon can also be inspiring for other designers, furthermore, it can help the development of the theory of the relation of design and research.

7.3.2 Limitations of the Methods

In this research, it is neglected that the water in the canals are not completely still, it is observed as very slowly flowing, so the cooling effect of the design principles is a little down-streamed in reality. As the down-streamed distance is dependent on too many various and complex factors, it is not feasible to be taken into account in this thesis. Also because the speed of the water is negligible according to my personal observation, and the heat exchanging process can already be finished before the water going far with the good ventilation in the designs. The influencing factors can be many, for example the flowing speed itself already depends on many factors like the volume of the section of canal, the recent precipitation, and so forth, not to mention the ever changing weather condition. It can be taken into consideration in the further detailed research

The necessity of Free-form design loop is more lying in the designing process. When I was so focused only on the cooling effect during the Additively Integrated Design Loop, I found it quite hard to jump out of the box of the “logical thinking”, and to improve the from the Additively Integrated Designs. I met a bottleneck there and I suppose it usually happens when designers have to focus on rational scientific problems. Then the Free-style Form Design Loop was an ice-breaker to free myself from all the rationales and mechanisms that were restraining my imagination, and help me to move on to the next design stage. This designing process could be inspiring for other designers who meet the similar situation. But the contribution of this design loop to the content of the final design principles is negligible.

7.3.3 Strengths & Weaknesses of Final Designs

As aforementioned, the final designs are much focused on cooling effect, so with less other constrains they are quite creative and effective on cooling as the strengths. However, that also means they are relatively less feasible compared to more ordinary designs. Furthermore, the aesthetical aspect is not researched for the final designs. For instance, the solar fans seem too novel and energy consuming, but they are very effective compared to passive interventions of ventilation, like making use of the regional wind (which will be barely effective due to the week wind in summer) and using solar radiation to heat up a part of the air (which is too unpredictable and inefficient compared to the efficient use of solar energy by the solar fans).

Just like the situations of Canal 3-1-1 and 3-2-1 are similar to Canal 1-1’s, there are other canal situations that does not require modification or only need minor modification to apply the final designs. The designs are not final fixed products, they are representative recommendations that can be applied to multiple series of canals. This is the strength of them, however they neglected a lot of detailed characteristics that one canal can have. As the test-beds are generalized from canals, they took the average of all the canal figures. In reality, the figures like the gaps of the trees, the heights of the houses, the width of the roads, the orientation of the canal, etc. are various everywhere. Aside from that, different sections of canals may have different social functions. For instance there are shops, restaurants, café, etc. in the residential area, they require different detailed designs. This is the weakness of the final designs.

7.3.4 Scientific Significance

The scientific significance of this thesis would be the contribution to the knowledge of landscape architecture and urban design on truly cooling urban water bodies. Academically, the thesis tested the RTD research process thoroughly, and added new knowledge to it by recovering the way to control the research focus by modifying the process like the timing to put certain criteria. Landscape architecturally, the thesis not only provides design criteria for truly cooling water body, but also provides recommended designs and design principles for representative urban water body types.

7.3.5 Social Impact

The social significance of the research lies in the improvement of the thermal comfort during warm periods around residential areas. It will refresh the way of decision making in city planning.

The designs principles can be easily incorporated with sustainable energy strategy. The solar fans that are used are capable of generating more energy than needed within the designs themselves. In the cooling mechanisms, shading is the most prime one. If solar energy is the main source of creating heat-stress, by only reflecting and blocking it is actually a waste. Storing and making use of solar energy while shading is smarter. In this sense, heat-stress mitigating can be in line with energy sustaining. When implemented, it can be balanced between the cooling effect and energy generating.

The recommended interventions are also very important to the water retention. As the water retention for potential flooding need more space for water, and lead to more urban water bodies. The heat-stress that is created by water bodies in nights will be more severe. The interventions will solve that problem.

7.4 Recommendation

For the municipalities of Utrecht and other Dutch water cities, the potential clients of this thesis, there are several recommendations.

Firstly, it is very important that from now on, the decision making that are concerning the urban water bodies is aware of the potential impact on future urban climate, especially the rising urban heat-stress.

Secondly, it is recommended for the water cities to have the climatope map of the city that is referred to in this thesis, to find out the current and potential future problematic areas concerning climate, especially the urban heat-stress. The problems include urban heat-stress, wind blocking or too strong wind, and urban flooding.

Lastly, the water bodies in the intersections of residential and high-heat stress areas are recommended to be designed following the similar RTD process of this thesis. They are also of course very welcome to be integrated with the city sustainable energy strategy, and water retention strategy.

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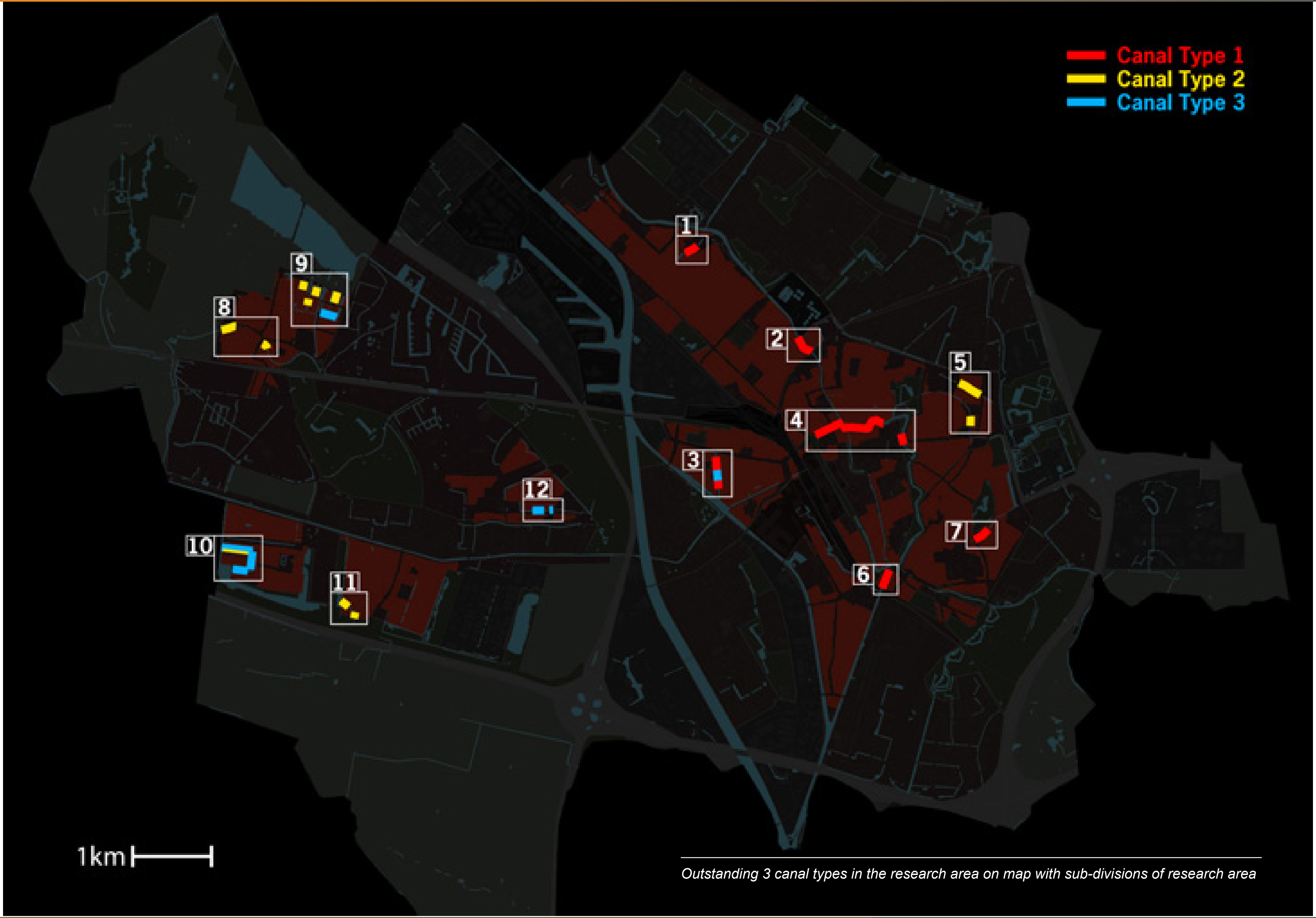
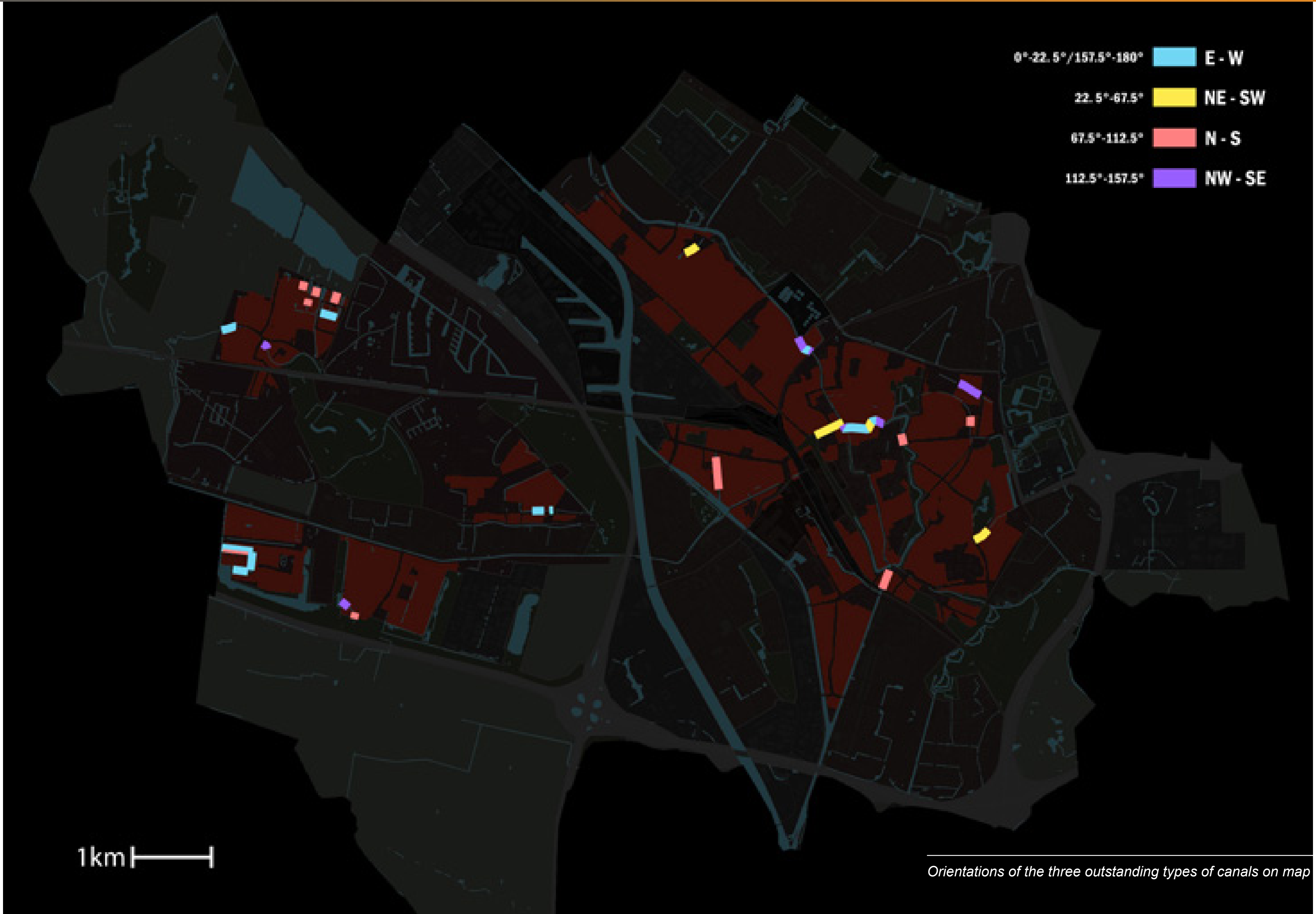
Appendix


treet View - Aug 2015
Google
Image capture: Aug 2015 © 2015 Google Terms Privacy

Appendix I

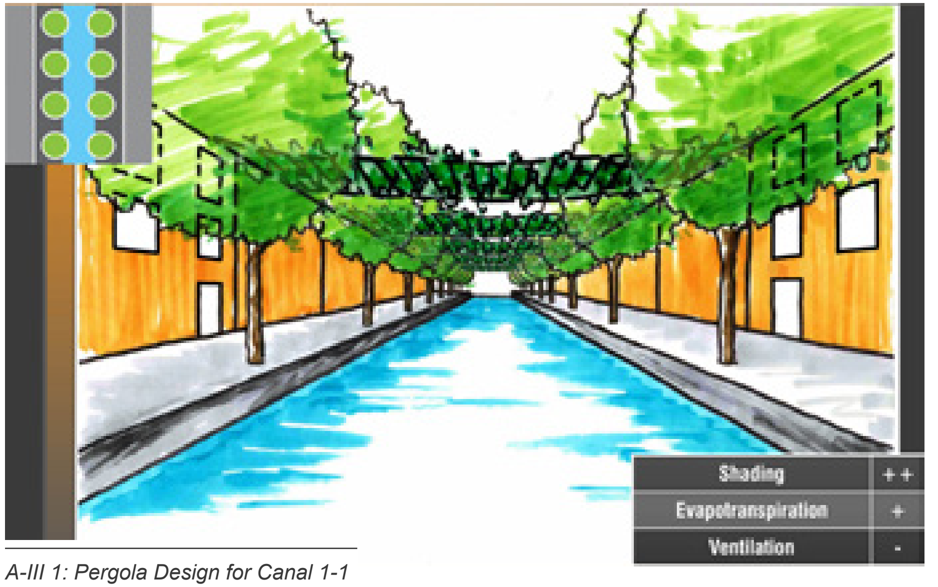


Outstanding 3 canal types in the research area on map with sub-divisions of research area

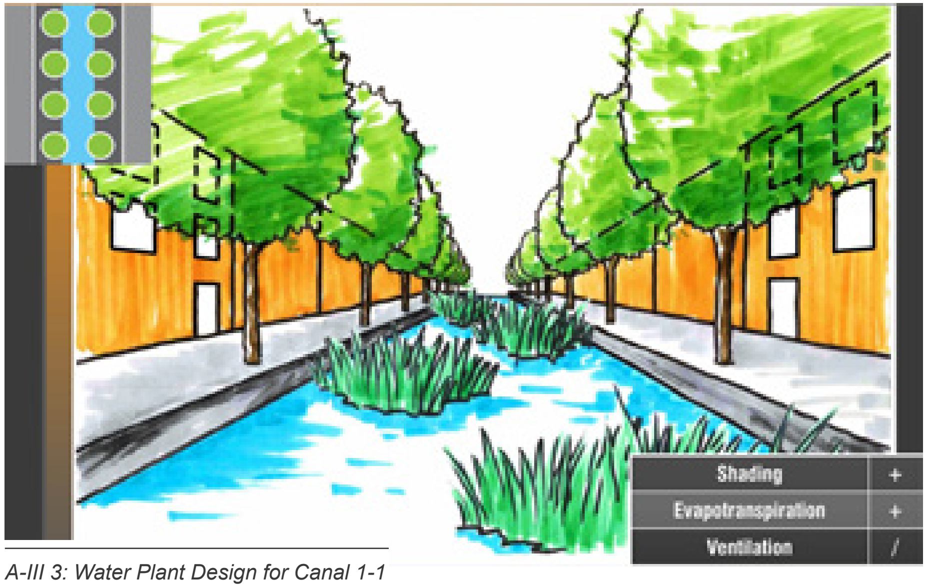


Orientations of the three outstanding types of canals on map

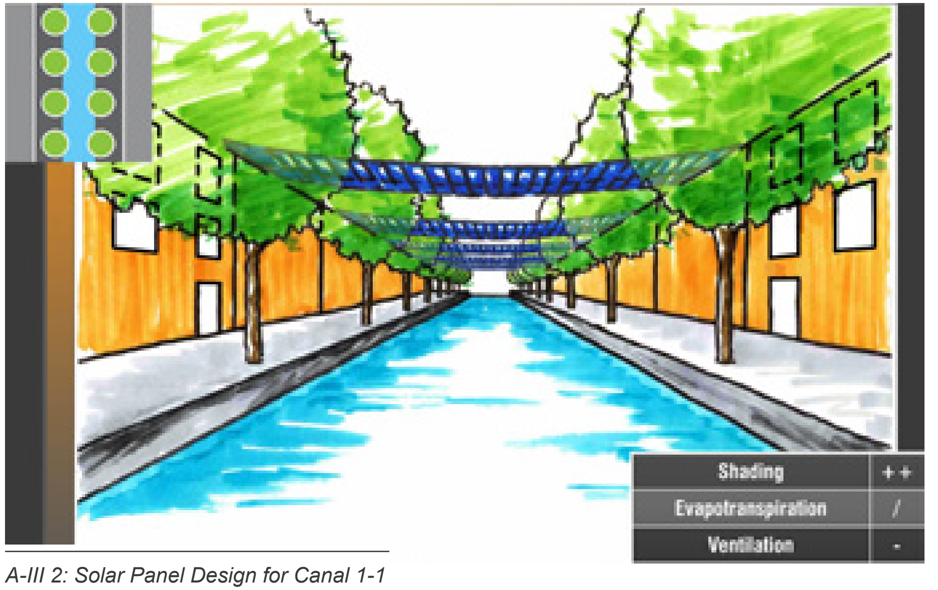
Appendix III



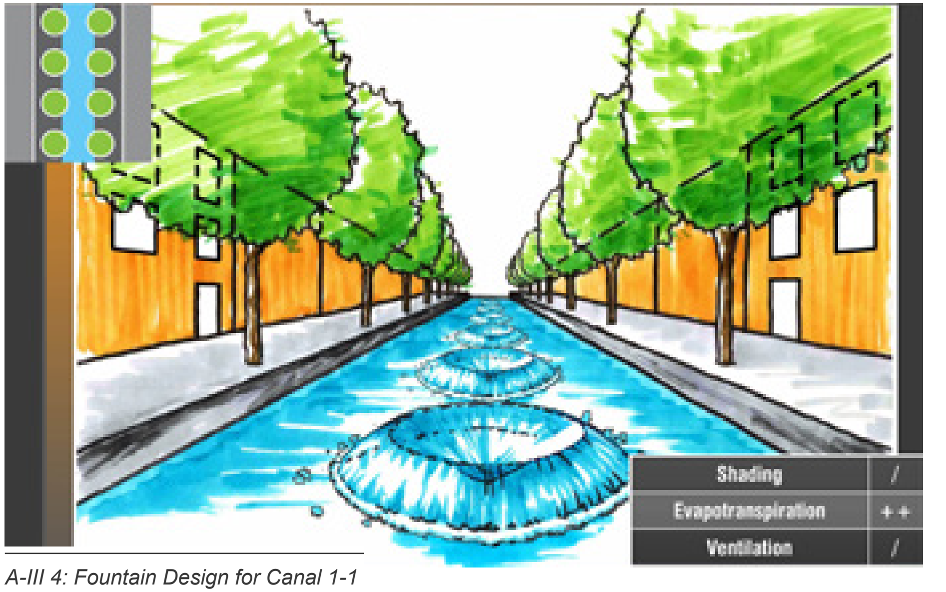
A-III 1: Pergola Design for Canal 1-1



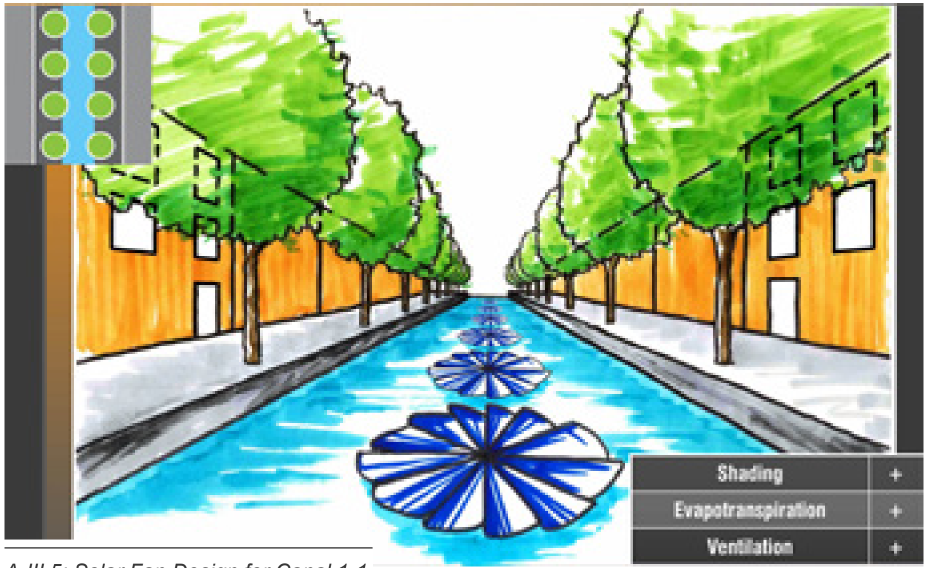
A-III 3: Water Plant Design for Canal 1-1



A-III 2: Solar Panel Design for Canal 1-1

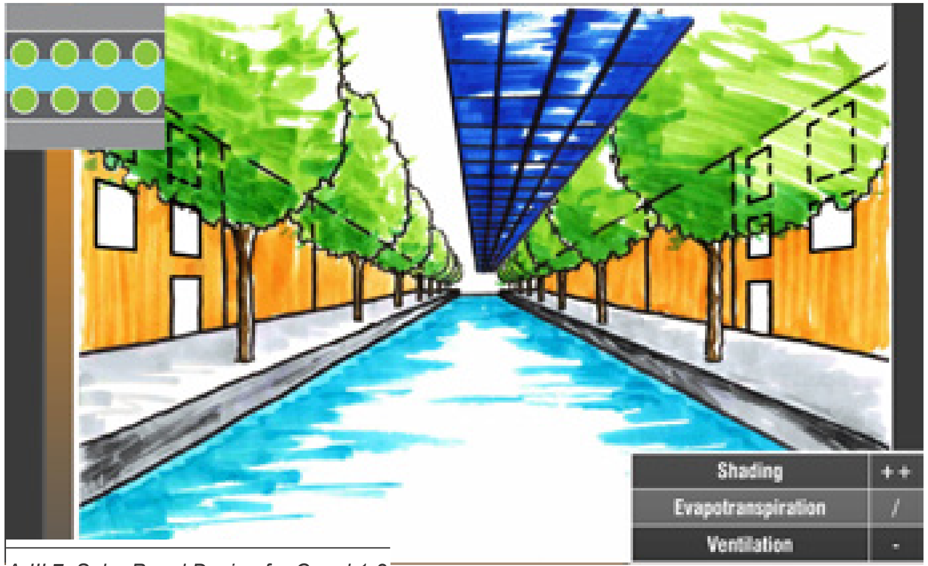


A-III 4: Fountain Design for Canal 1-1



A-III 5: Solar Fan Design for Canal 1-1

A-III 6: Pergola Design for Canal 1-2



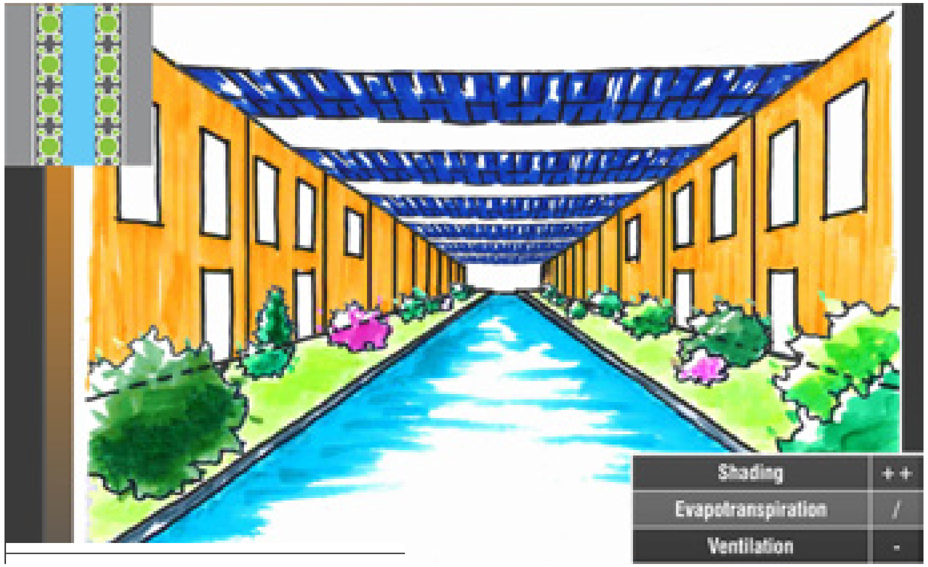
A-III 7: Solar Panel Design for Canal 1-2

A-III 8: Water Plant Design for Canal 1-2

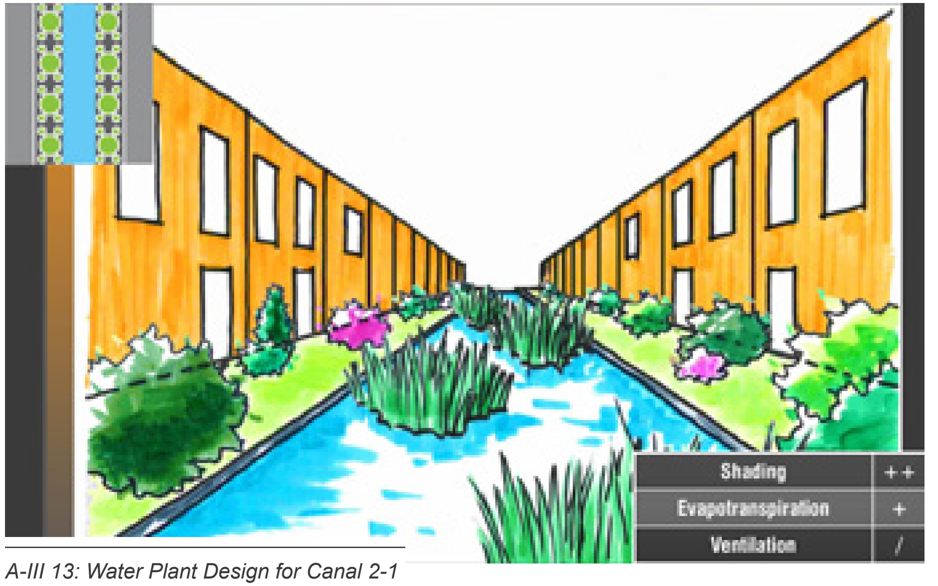
A-III 9: Fountain Design for Canal 1-2

A-III 11: Pergola Design for Canal 2-1

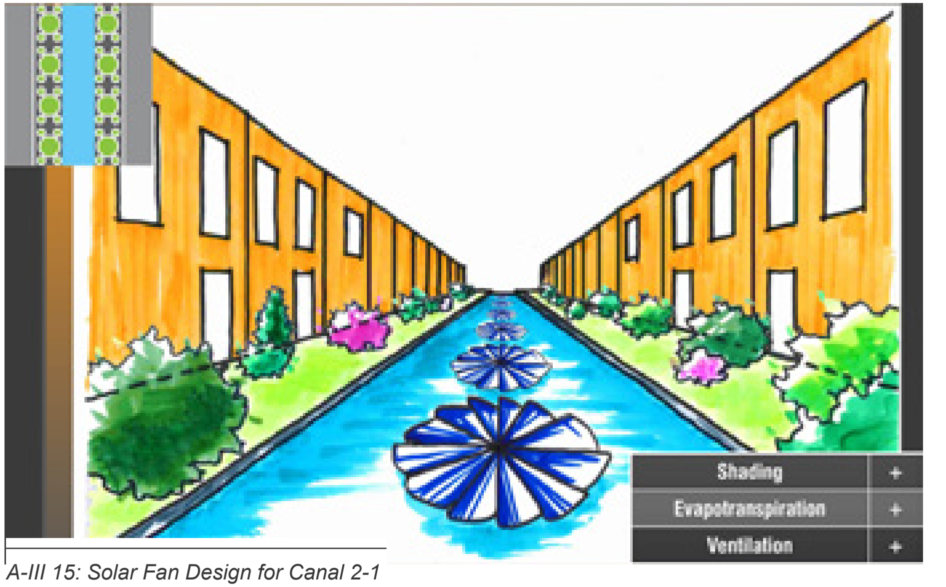
A-III 10: Solar Fan Design for Canal 1-2



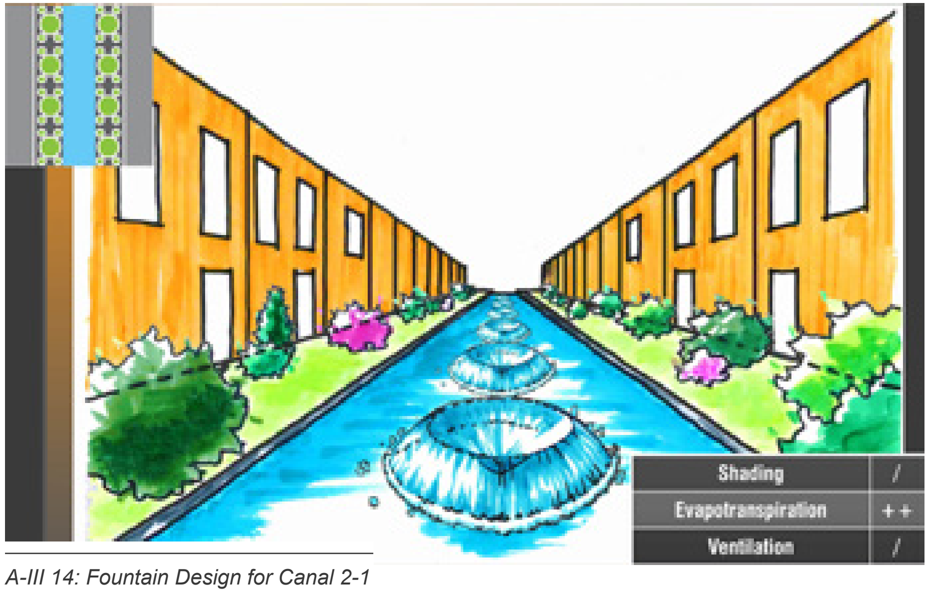
A-III 12: Solar Panel Design for Canal 2-1



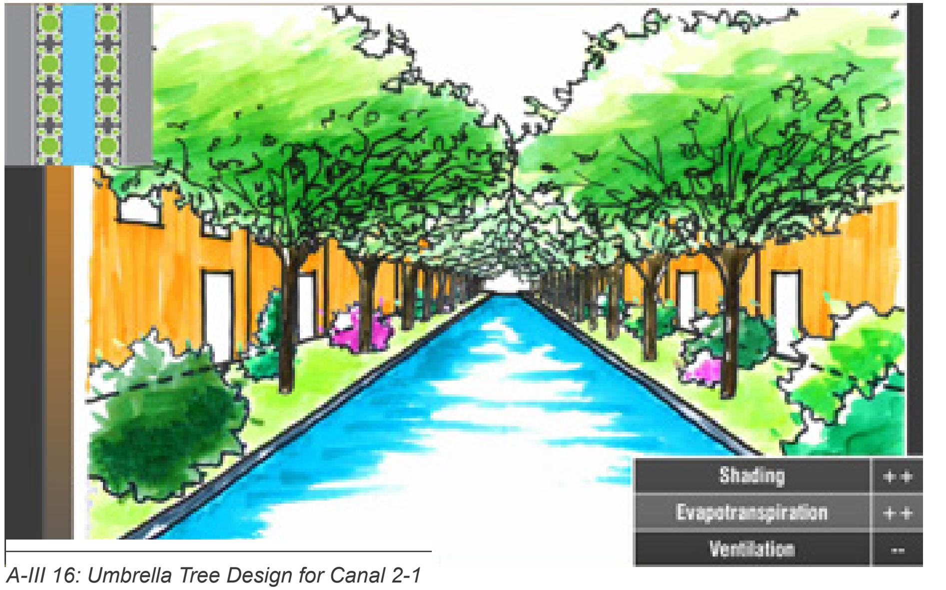
A-III 13: Water Plant Design for Canal 2-1



A-III 15: Solar Fan Design for Canal 2-1

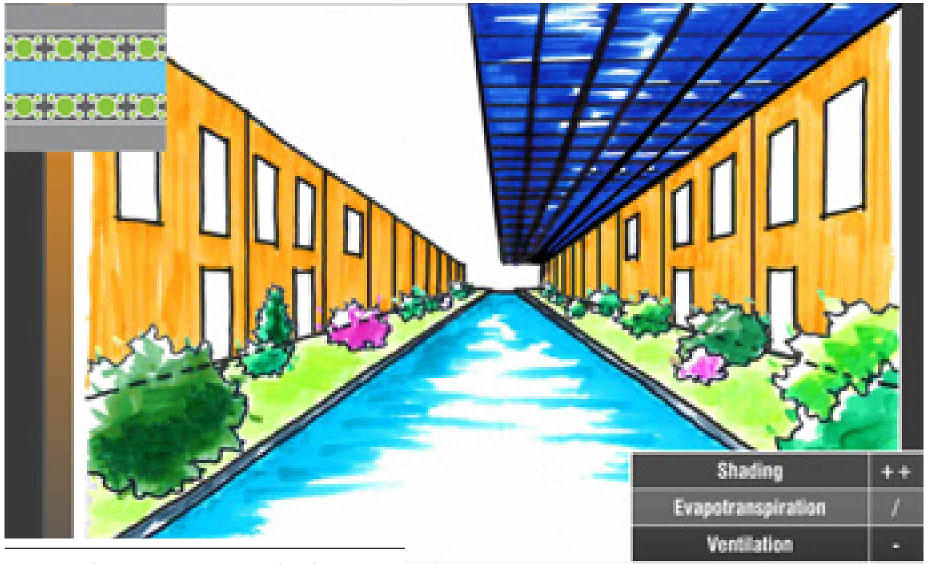


A-III 14: Fountain Design for Canal 2-1

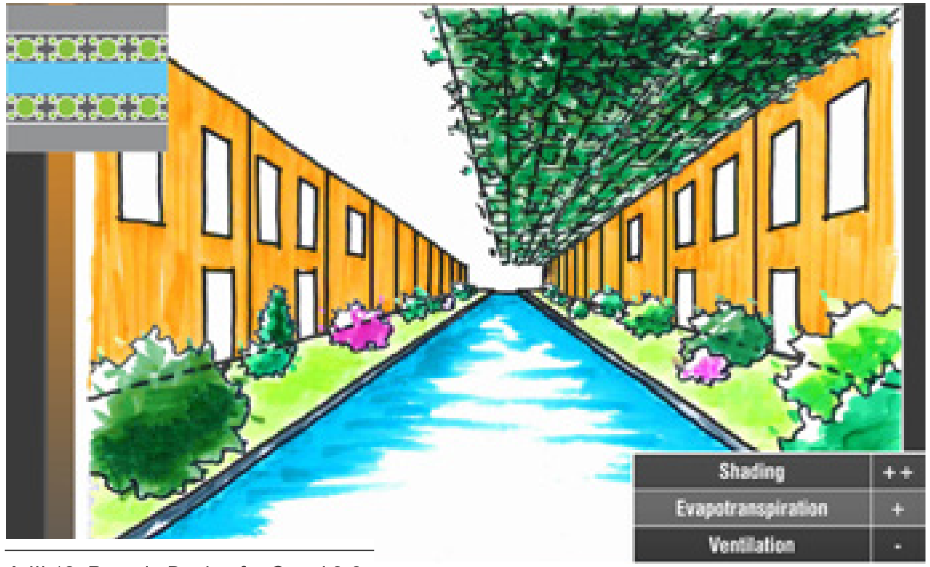


A-III 16: Umbrella Tree Design for Canal 2-1

A-III 17: Dawn Redwood Design for Canal 2-1

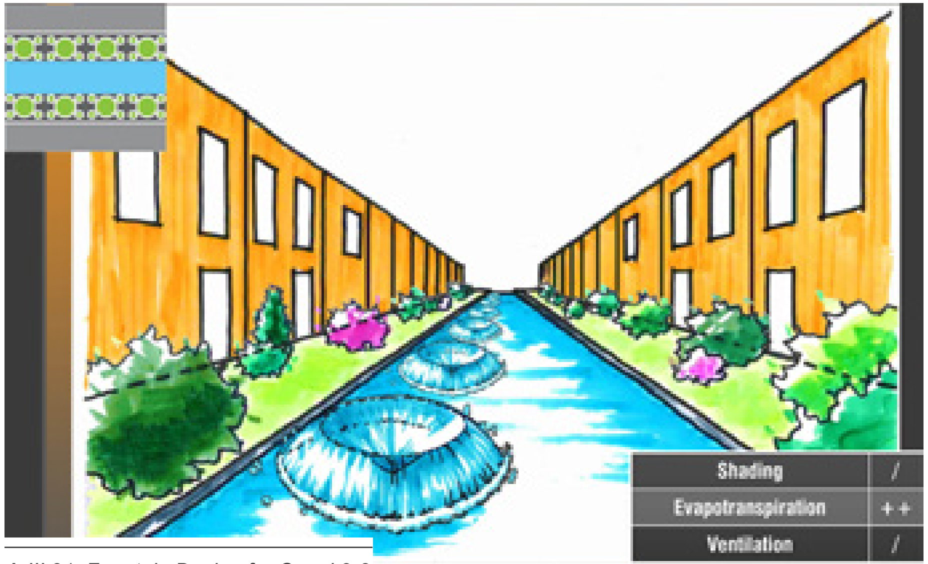


A-III 19: Solar Panel Design for Canal 2-2



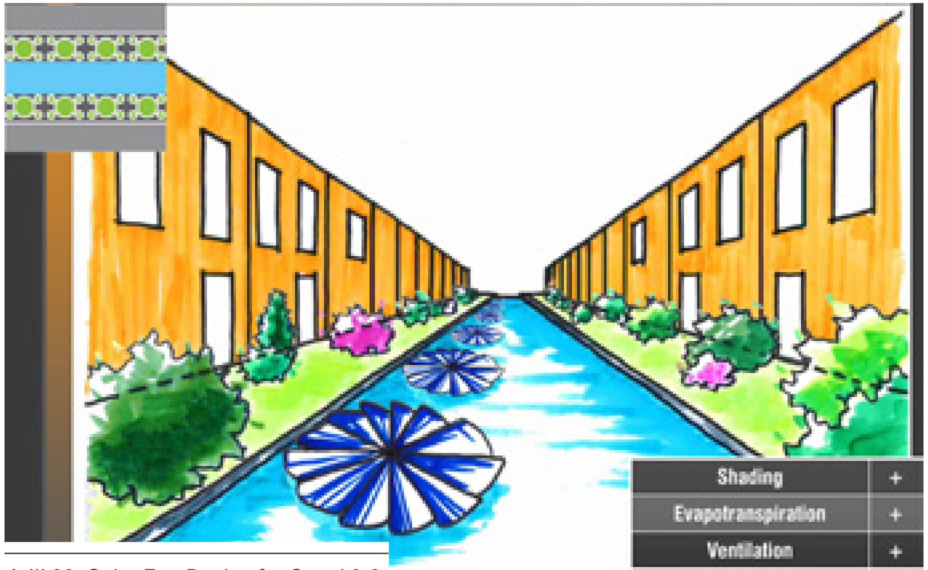
A-III 18: Pergola Design for Canal 2-2

A-III 20: Water Plant Design for Canal 2-2

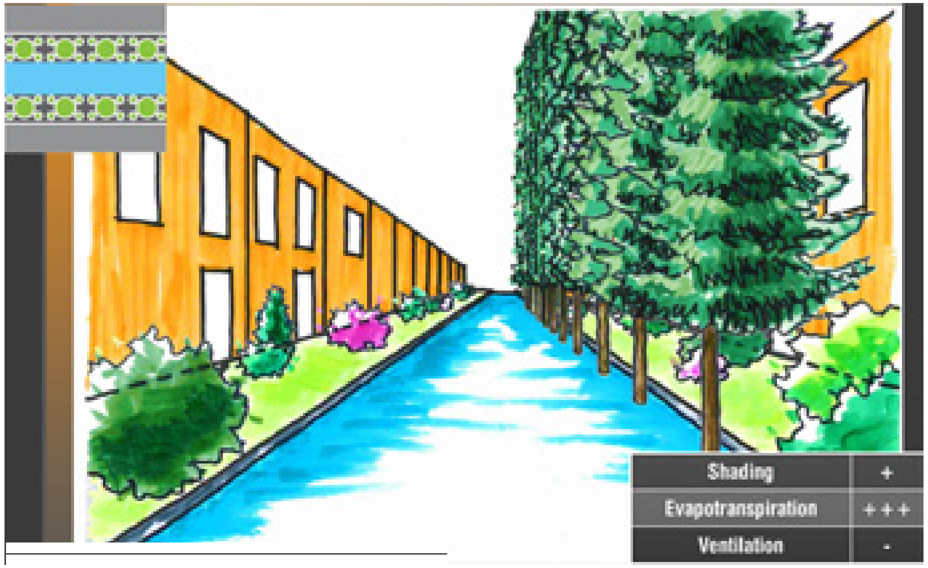


A-III 21: Fountain Design for Canal 2-2

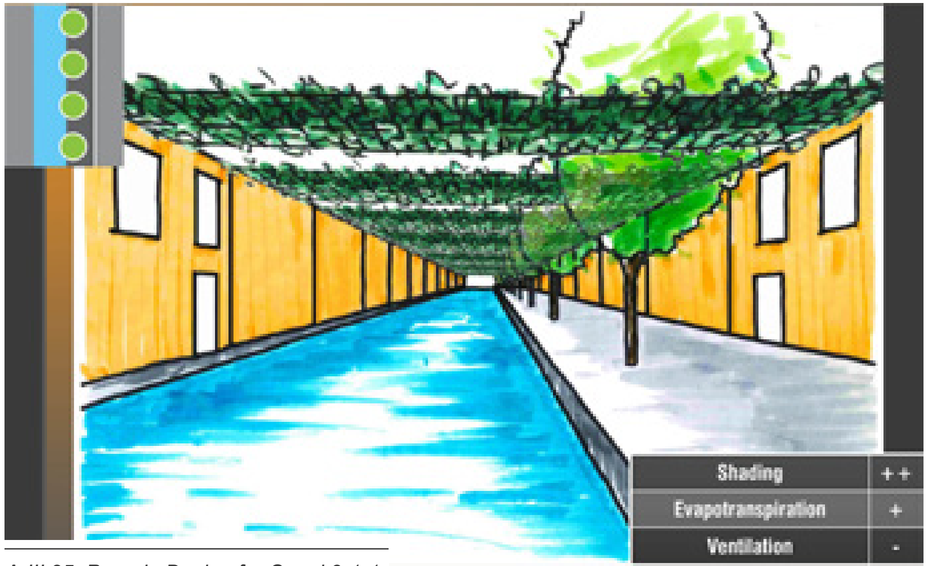
A-III 23: Umbrella Tree Design for Canal 2-2



A-III 22: Solar Fan Design for Canal 2-2

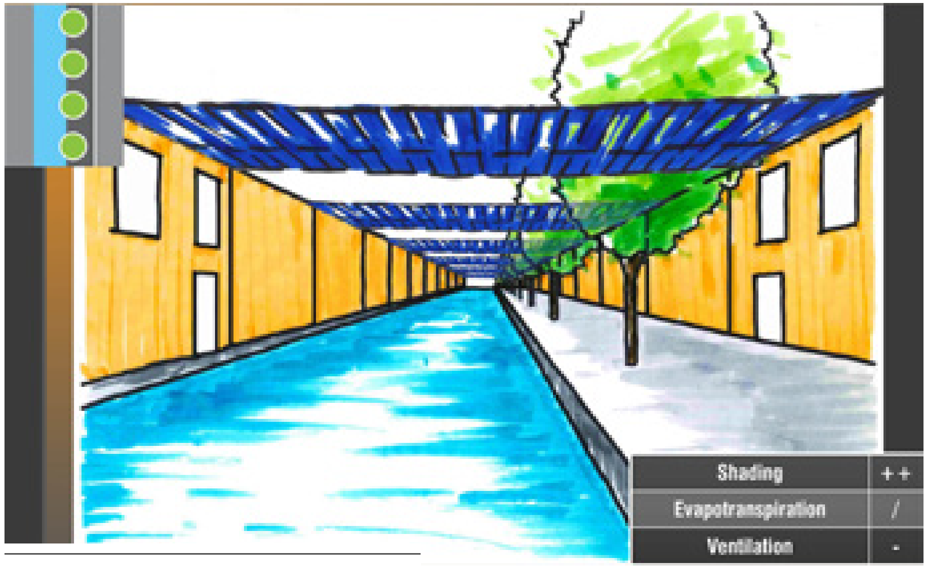


A-III 24: Dawn Redwood Design for Canal 2-2

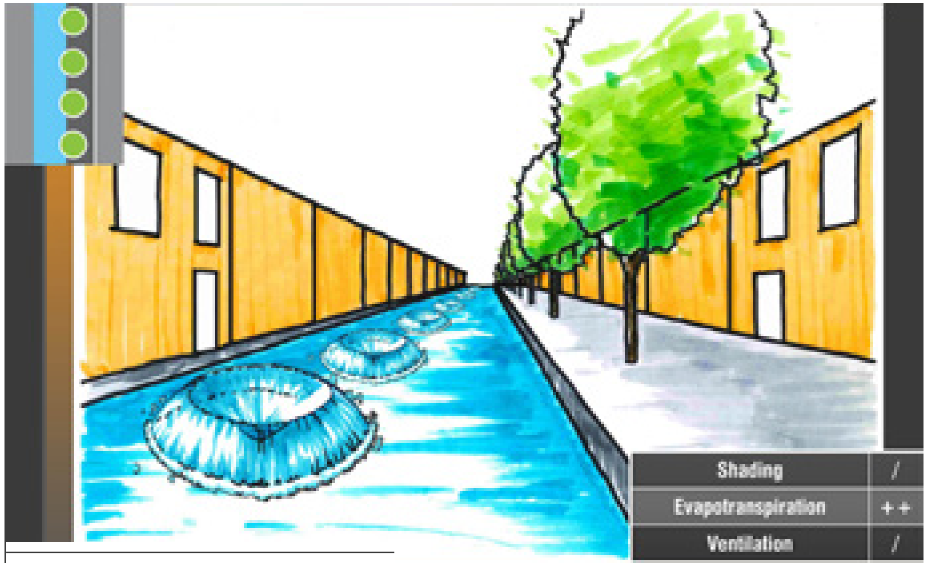


A-III 25: Pergola Design for Canal 3-1-1

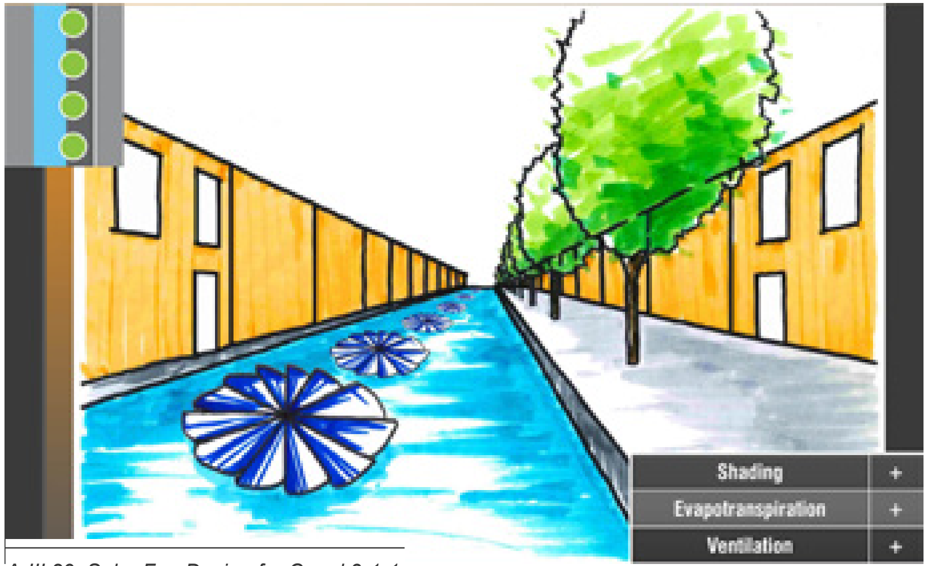
A-III 27: Water Plant Design for Canal 3-1-1



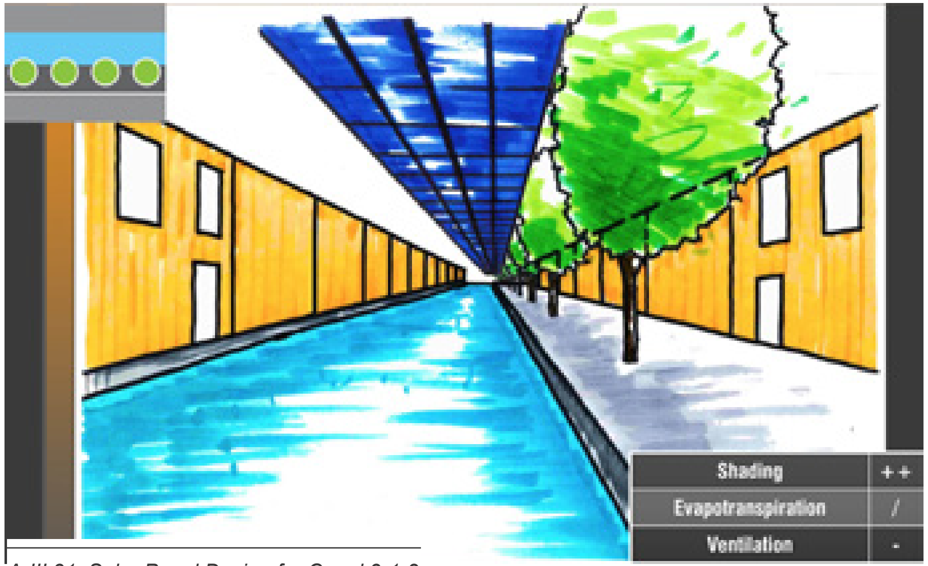
A-III 26: Solar Panel Design for Canal 3-1-1



A-III 28: Fountain Design for Canal 3-1-1

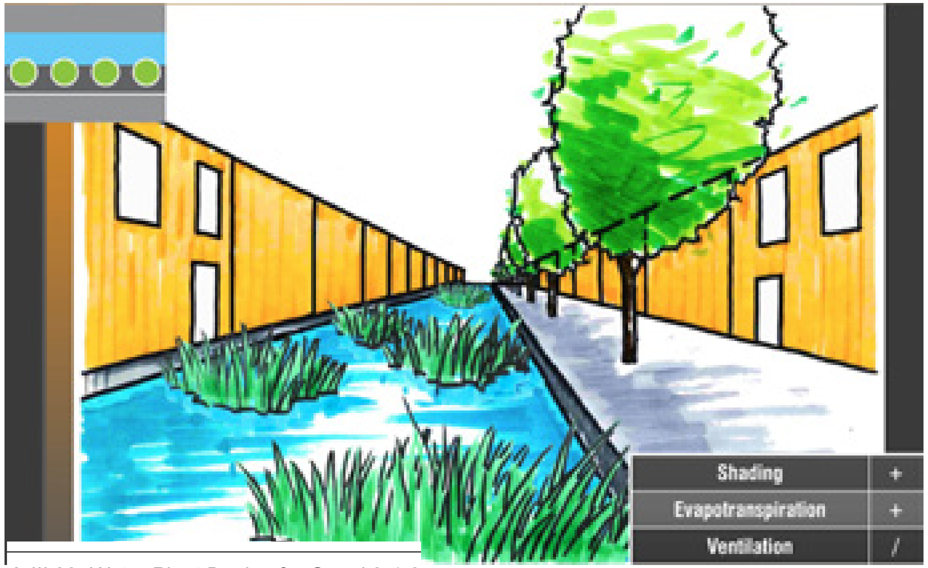


A-III 29: Solar Fan Design for Canal 3-1-1



A-III 31: Solar Panel Design for Canal 3-1-2

A-III 30: Pergola Design for Canal 3-1-2



A-III 32: Water Plant Design for Canal 3-1-2

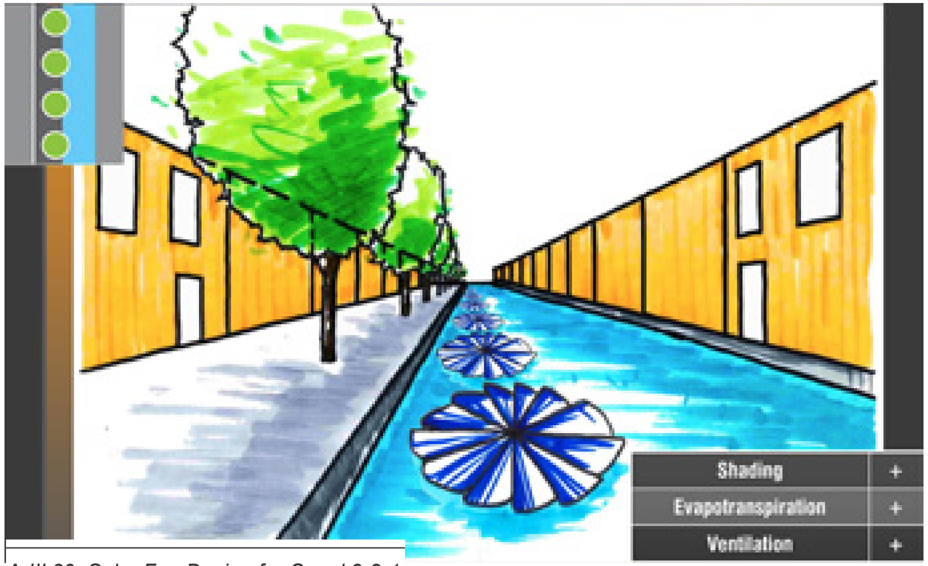
A-III 33: Fountain Design for Canal 3-1-2

A-III 35: Pergola Design for Canal 3-2-1

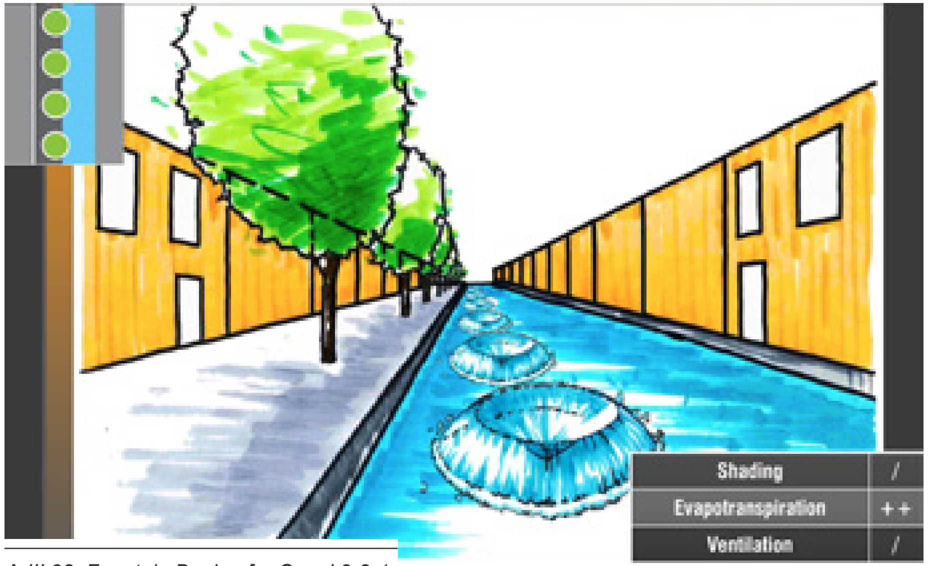
A-III 34: Solar Fan Design for Canal 3-1-2

A-III 36: Solar Fan Design for Canal 3-2-1

A-III 37: Water Plant Design for Canal 3-2-1



A-III 39: Solar Fan Design for Canal 3-2-1



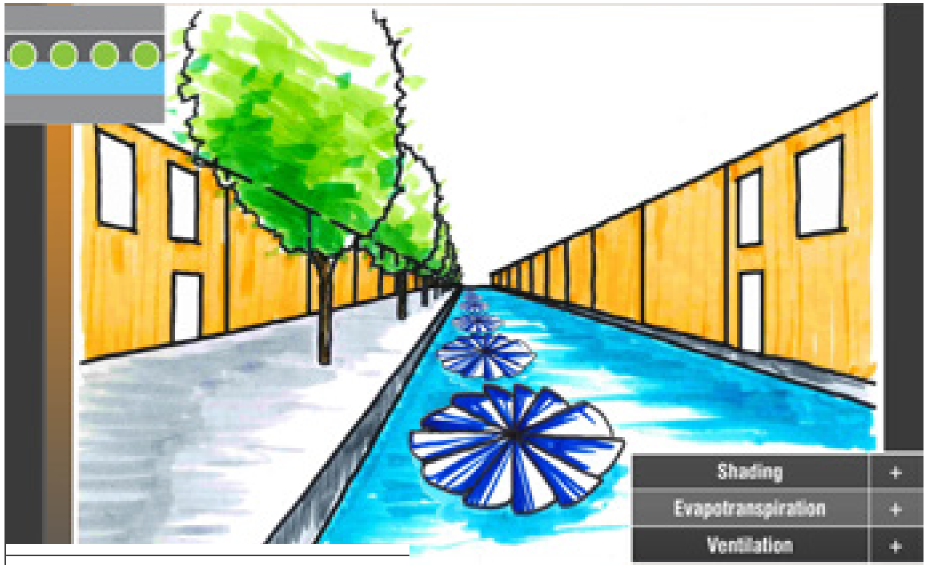
A-III 38: Fountain Design for Canal 3-2-1

A-III 40: Pergola Design for Canal 3-2-2

A-III 41: Solar Panel Design for Canal 3-2-2

A-III 43: Fountain Design for Canal 3-2-2

A-III 42: Water Plant Design for Canal 3-2-2



A-III 44: Solar Fan Design for Canal 3-2-2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