Creating prototypes for cooling urban water bodies

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Abstract

When addressing urban heat problems, climate-conscious urban design has been assuming that urban water bodies such as canals, ditches or ponds cool down their surroundings. Recent research shows that this is not necessarily the case and that urban water bodies may actually have a warming effect, particularly during late summer season nights. There are however indications that water can have a cooling potential if brought together with the right shading, evaporation and ventilation strategies. Yet, it is not clear how this should be achieved. Knowledge on such spatial configurations should thus be developed and made available to design practice. This challenge is directly addressed by the "REALCOOL" project, a research aiming to define design prototypes showing the physical processes behind the effective cooling potential of urban water bodies, that design professionals can take as conceptual design frameworks.

This paper addresses the first loop of the REALCOOL's research through designing (RTD) method, in particular how different prototype design options were created and tested. We address the identification of testbeds – 3D visualisations of common Dutch urban water bodies upon which the design experiments were conducted through different configurations of shading, evaporation and ventilation strategies. These experiments were targeted at improving outdoor human thermal sensation. We further present how the different design options were tested against micrometeorological simulations, expert judgements and external feedback from design offices, consultants and municipalities. We explore the aesthetical, functional, economical and maintenance challenges upon adding a thermal regulation role to the common infrastructural and/or aesthetical conception of urban water bodies. The paper concludes about the cooling effectiveness of the outcomes of this first RTD loop and about the way these will inform the subsequent RTD loops

Introduction

In climate-conscious urban design, urban water bodies such as ponds, canals or shallow water bodies are assumed to cool down their surroundings. This assertion is usually based on scientific literature claiming that urban water bodies have a cooling effect [1, 2]. However, recent research shows that the cooling effect of most common urban water bodies in warm summer periods is quite limited during daytime and that water bodies may cause a night-time warming effect [3, 4]. A study analysing the surface temperatures of the 73 largest Dutch cities showed that those with a larger share of water surface have a larger night time surface heat island effect [5].

While the nocturnal warming effect of water bodies may exacerbate urban nocturnal heat during late summer and autumn [6], under specific circumstances water can indeed have a cooling effect. There is a body of knowledge on the potential of water to reduce the heat island effect mainly brought by the fields of meteorology, bioclimatic design, water-sensitive urban design and water management [2, 3, 7–10]. For example, Nishimura et al. [11] showed that water mist and waterfall features can reduce air temperature by 1-2 °C on the leeward side up to a distance of 35 meters. Robitu et al. [12] confirmed the cooling potential of combining vegetation with water. There are indications that shading water, vaporising water, and providing proper ventilation might help to keep urban water bodies and their surroundings cooler [11, 13, 14]. Yet, it is unknown how these strategies can be combined to achieve an effective cooling effect around urban water bodies. The implications of these combinations on criteria such as aesthetics, costs or maintenance are also unknown.

The challenge of designing cooling water bodies is addressed by the 'Really cooling water bodies in cities' (REALCOOL) project, a Research Through Designing (RTD) project aiming to define design prototypes showing the physical processes behind the effective cooling potential of urban water bodies. 'Prototype' should herewith be understood as a research output illustrating or elaborating a new perspective through design, resulting from a prototyping process which is itself a means of inquiry [15]. The REALCOOL prototypes will consist of evidence-based animated 3D scenes aimed at informing, not determining, design decisions. This paper addresses the way different combinations of urban water bodies with shading, evaporation and ventilation strategies targeted at improving thermal sensation were created and tested during the first loop of this RTD method.

Methods and tools

The RTD process, based on Lenzholzer et al. (2013), Breen (2002), and de Jong and van der Voordt (2002), is well-suited to the design-led objective of REALCOOL. RTD is a research where 'designs are not made intuitively, but based on study (experimental design study), recording, examination and evaluation' [19]. The defined methodological steps are closely related to this (Figure 1): Step after step, this iterative cumulative process will allow achieving consistent final design prototypes.

Four research loops are included to arrive at the final design prototypes. Each loop is based on a systematic sequence of designing (different combinations of shading, evaporation and ventilation around water), testing (educated-guesses and micrometeorological simulations) and assessing (external cross-sector feedback). This section describes the methodological steps and tools of the RTD's first loop.

2.1. Preparatory work

The research started with an inventory of representative Dutch urban water bodies in order to set the design testbeds — 3D spatial reference situations upon which the design prototypes would be created. Nine cities across the Netherlands (Amsterdam, Delft, Den Haag, Dordrecht, Groningen, Leeuwarden, Rotterdam, 's-Hertogenbosch and Utrecht) were selected based on soil type. Two main soil types were distinguished: clay and peat, where more permanent surface water (prone to heat up) can be found. All cities had a clear urban heat island effect according to the Dutch Climate

Impact Atlas (Klimaateffectatlas - http://www.klimaateffectatlas.nl/nl/). Geographic information system maps on land uses combined with the climatope definitions by Lenzholzer (2015), and Google Earth views were used for identifying the most frequent urban water bodies within heat-prone areas in these cities: The longest or largest water bodies within compact urban areas with high daytime and night-time use. A spatial analysis followed through *in situ* observations, measurements, photos and mapping.

The relevance of the resulting 33 water body types was critically assessed by the research team and an external committee of scientific advisors and representatives from consultancies, urban and landscape design offices, and municipalities (NWO Domain Applied and Engineering Sciences user committee). The number of water body types was brought down to 8 and called the REALCOOL testbeds (Table 1). These were categorised according to layout as 'Gracht' (canal), 'Singel' (boulevard), 'Sloot' (ditch) or 'Vijver' (pond).

Two simulation tools, Envi-met [21] and the Cool Water Tool [22], were simultaneously prepared. ENVI-met is a model widely used to describe microclimate and human thermal comfort, giving detailed spatial patterns of microclimatic conditions of urban environments. The Cool Water Tool simulates the water energy balance and therefore the water temperature of shallow water bodies under the influence of the weather. This tool is suitable to generate realistic time series of water temperature. Here, the Cool Water Tool was used to provide realistic initial conditions of the water temperature in Envi-met for a hot summer day, while Envi-met was used to assess the microclimatological performance of the water bodies. To this end, the Envi-met Winter1617 (V4.1.3) release was applied, which enables simulating turbulence mixing in the water layer. Water and air temperature, and the PET — Physiological Equivalent Temperature Index [23] were the evaluation variables. The thermal effect of water was simulated for a typical tropical day (Tmax >= 30 °C) and the following night, when heat stress is severely felt. Average values for air temperature, relative humidity, wind speed, wind direction and cloudiness for tropical days based on data from De Bilt (1981-2010) were used. The summer solstice (around 21st June) was selected for the simulation because of its most critical (maximum) sun angle. Solar noon, in the Netherlands 1.40 p.m., was used to determine the shading patterns at the testbeds through 3D visualisations.

2.2. Designing

The design steps are the crucial component of the RTD process and were carefully prepared prior to designing. A design framework, i.e. the principles anchoring the design options made across the different testbeds, was defined for preventing randomness:

- *East-west (EW) and north-south (NS) orientations, for exploring design solutions addressing contrasting exposures to solar radiation.* This choice doubled the number of testbeds to 16. In the northern hemisphere, at solar noon, EW-oriented canyons have the north side fully exposed to the sun and the south side is self-shaded all day long. In NS-oriented canyons both sides have the same amount of sun hours a day whilst the centre of the canyon is fully exposed at solar noon. Blocking short-wave radiation at the sunlit areas is crucial. The shading patterns identified at the testbeds were used for determining the dimension of these areas. Design Principle 1 — for EW oriented spaces, to increase effective shading over the northern part of the water body and, for NS orientations, over the central part.
- *Vegetation and water features for increasing evaporation*. Vegetation has the largest cooling impact on the extremely hot days [24, 25] due to the combination of shading and evapotranspiration. Moving water or, especially, spraying it effectively cools the environment [20]. Design Principle 2 — to increase evapotranspiration through vegetation and evaporation through water features over the

whole water body.

- *East as the reference wind direction, shown to be the predominant direction during tropical days according to the data retrieved from De Bilt.* This is in line with the argument that easterly winds are 'typically prevailing during summer heat waves in Western Europe' [9]. Wind has three effects: it stimulates turbulent exchange and evaporative heat losses, it transports air above the water surface to the environment around it, and it reduces the PET during heat stress periods. Therefore, during a tropical day it is preferable to allow air flow over the water body. Design Principle 3 — to allow wind to flow over the whole water body.
- *Water at the centre of the design experiments (scope of the REALCOOL).* Design Principle 4 is thus developing design solutions directly interacting with water, either reducing water temperature or resulting in a synergetic cooling effect. Trees, shrubs, aquatic plants, vines, green walls, shading devices, and water features (fountains and water mist) were considered the most suitable design elements. The importance of other elements was acknowledged. For instance, paving materials can significantly influence the thermal performance of an outdoor space [26]. However, these were not considered here because they do not interact with water directly.

A design concept guided the combination of design elements. For the first loop, this concept dealt with achieving a maximum cooling effect through a strictly bioclimatic approach, that is, without considering other criteria like aesthetics or maintenance requirements. Traffic and water flow were the only non-bioclimatic parameters considered. Other overarching urban design parameters will be integrated in the second research loop. The designing took shape through sketching, 2D drawings, 3D visualisations, and physical models. Many design possibilities were systematically narrowed down through a design matrix rating the efficiency of the design solutions in meeting the goal of the research and

the design concept (Figure 2)
In Figure 2, the design elements, on the vertical axis, are cross-related to the research's design strategies, on the horizontal axis using a qualitative five-point rating scale: -2 (very negative), -1 (negative), 0 (neutral), 1 (good) and 2 (very good). The designs were revised multiple times till the maximum rating was achieved. This revision went up to a point where no further options were offered by the layout of the testbeds. Note that we focused on the use of natural elements since the cooling potential and multiple benefits of plants in fields like urban ecology or psychological processes make it more attractive than artificial devices. Neutral impacts were considered on the positive side of the scale whenever no or negligible effects were actually desirable, e.g. inducing no changes to ventilation as a means of allowing wind to flow.

2.3. Testing

The testing of designs commenced with the educated-guesses, i.e. a critical discussion based on experts' judgement and scientific evidence, on their cooling potential. We focused on the most influential biometeorological issues. The use of physical models of the designs facilitated the communication and allowed getting a better understanding on microclimatic effects. In some cases, an abundant increase of vegetation for shading was considered to hamper ventilation and thus evaporation, and also night-time cooling by long-wave radiation emission. This would be counter-productive and needed revision. The educated-guesses strongly impacted designs in the sense of a more synergetic combination of strategies. As an example, in GRACHT1 EW (Figure 3) a row of trees and shrubs on planting structures projected over the water is installed on the northern part of the water (Design Principles 1 and 2); aquatic plants, fountains and water mist dispensers are also placed along this area at the water level (Design Principles 1 and 2); Design Principle 3 is addressed by the quantity and irregular positioning of plants. GRACHT1 NS receives the same solutions, the only difference

being the focus on the central part of the water body. Here, trees and shrubs are grouped in small 'islands'.
Testing also comprised micrometeorological simulations evaluating the current cooling, warming or neutral effects of the testbeds and its implications on the design. The current microclimatic performance of the testbeds and of a no-water scenario (a hypothetical situation where water is removed from the testbeds and the contiguous paving solutions extended up to its central axis) were simulated. The outputs of these simulations show that (1) the daytime cooling effect at the testbeds is small and there is hardly any contribution to night-time warming or cooling; (2) that the differences between testbeds are small regarding cooling effects in air and water temperature; and (3) that the highest shading level leads to the coolest conditions (GRACHT3).

2.4. Assessment

The TTW second user committee (UC2) assessed the designs on overarching urban design criteria: aesthetical appeal, functional match, costs, and maintenance requirements. The committee members assessed the performance of the designs on each criterion using the five-point scale of the design matrix (Figure 2). In addition, the reasons underlying each assessment were collected. From the different assessments and underlying motivations the following conclusions could be drawn. The designs:

- Entail positive aesthetic qualities although these should be further explored. Should this potential be carefully addressed the designs can favour the image of the city or, otherwise, problems might arise on coherence and visual connections.
- Have a predominantly positive match with pre-existing functions and may even enhance them. If correctly explored, the designs may reinvent the common way people use urban water bodies.
- Entail higher capital investments which can, however, be offset by the cooling potential

of vegetation and its additional benefits.

- Entail higher maintenance requirements although these can be offset by the delivered amenities. The optimisation of maintenance issues should be further explored.

Due to the multidisciplinary background of the committee, these outcomes refer to consistent assumptions based on both academic and practical experience. Therefore, they defined the refinement principles for the subsequent designing stage (Table 2).

Discussion and Conclusions

This paper presented the first loop of a RTD process and focuses on its interim procedures and results. We highlight the smooth transition between the different stages, from the identification of testbeds to the refinement principles — the methodological steps confirmed initial assumptions and lead to designs which, irrespective the required improvements, constitute a reliable basis for conducting the following research loops. The communication within the multidisciplinary research team was eventually the most important tool. Several discussions between urban designers, meteorologists and water specialists were turning points in the research. At each discussion, the scientific assumptions behind the cooling potential of water bodies were growingly given maturity. The openness to the different interpretations, meanings and procedures from the different concurrent disciplines was fundamental for achieving meaningful results.

Finding the right balance between shading, evaporation and ventilation was a major challenge. How to increase shade without hampering ventilation or how to increase evaporation without compromising water flow are examples of questions addressed, which still need to be kept in mind throughout the whole RTD. The educated-guesses provided fundamental assumptions and the design matrix set the base for different experiments. In the next loop, the validity of the fundamental assumptions will be checked using further micrometeorological simulations. Moving to overarching urban design criteria, the following questions arise: how to increase vegetation without compromising aesthetics or function and even enhance them? How to offset costs and maintenance requirements which are necessarily higher compared to the testbeds? A compromise needs to be found between the generalized 'cooling' design solutions and overarching urban design criteria which are mostly site-dependent. Where are the solutions generalized and where do they become site-specific is a question to be further explored.

This loop came up with three relevant outcomes:

1. The testbeds have no relevant thermal effect, which confirms the need for developing really cooling water bodies in cities.
2. Shading seems to be the fundamental strategy for the cooling potential of water but also the major design challenge since it may compromise evaporation, ventilation and night-time cooling. Care should be given to the synergetic effect of strategies.
3. The iterative process resulted in designs that, based on rules of thumb, have an efficient cooling potential. Nevertheless, these should be further developed and quantified, as well as carefully brought together with aesthetical, functional, cost and maintenance criteria.

These conclusions provided the necessary refinement principles for the second RTD loop. The designing, testing and assessing stages of the first loop provided a consistent body of assumptions upon which to base the subsequent stages of the RTD. By systematically repeating its methodological steps, the designing process will be given systemic robustness, and scientific and practical relevance. By presenting the way we are conducting this RTD, we hope to contribute to developing the scientific debate within landscape architecture. Defining upfront a strong (yet flexible) strategy for preventing randomness, and openness to inter-disciplinary communication seem to be crucial factors for giving this discipline a more scientifically-relevant dimension.

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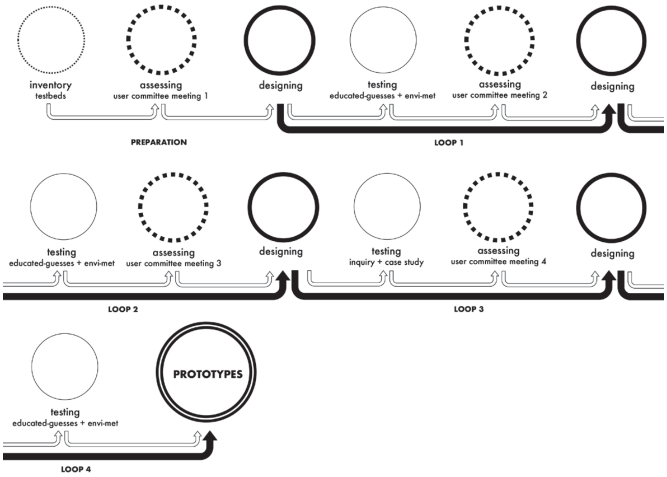


Figure 1. Methodological steps

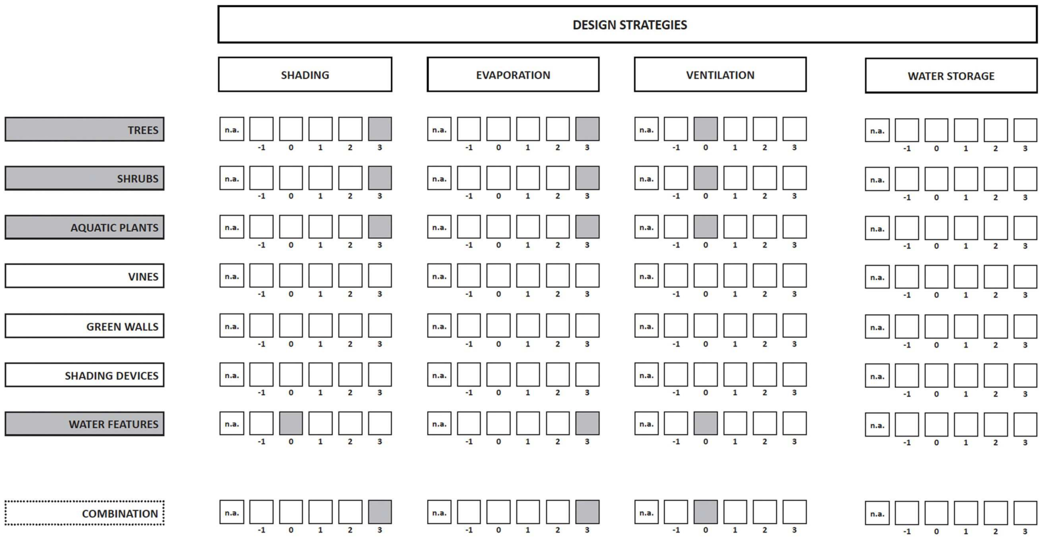


Figure 2. Design matrix for GRACHT1 EW

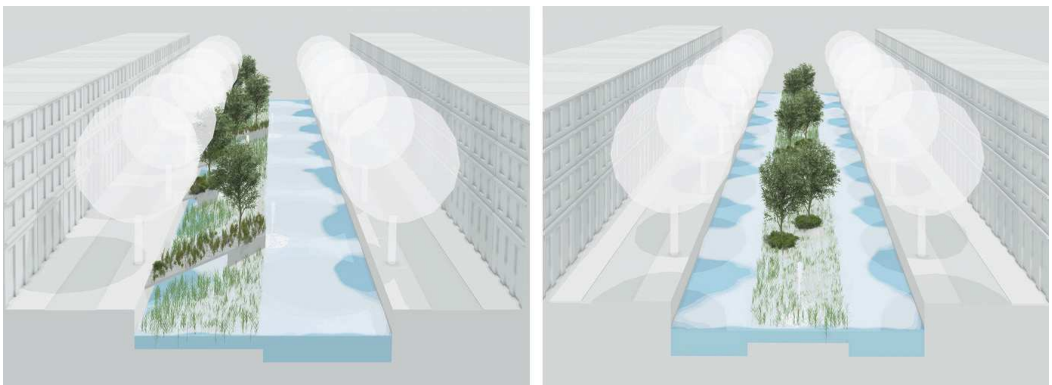
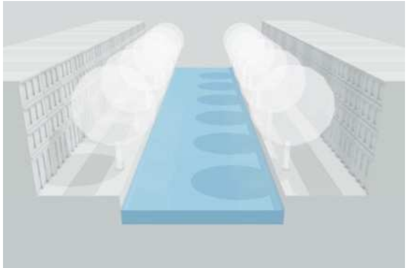
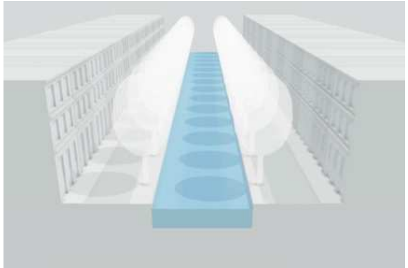


Figure 3. Designs for GRACHT1 EW (left) and GRACHT1 NS (right). Images credits: Jochen Muelder

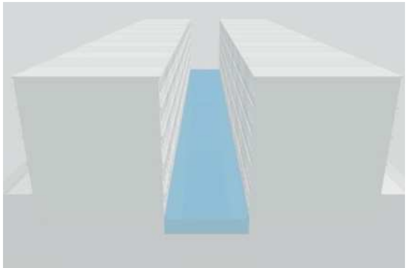
gracht



GRACHT1

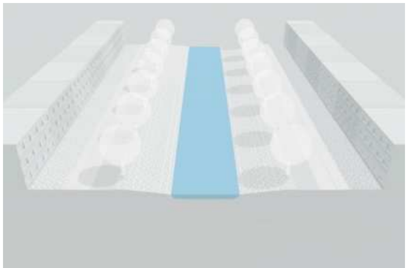


GRACHT2

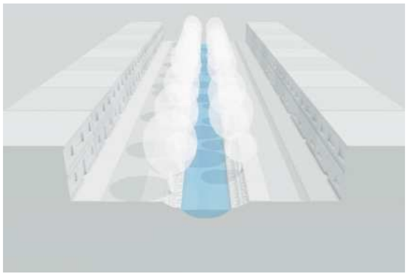


GRACHT3

singel

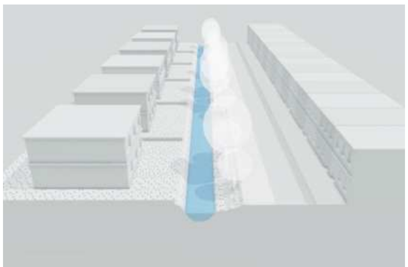


SINGEL1

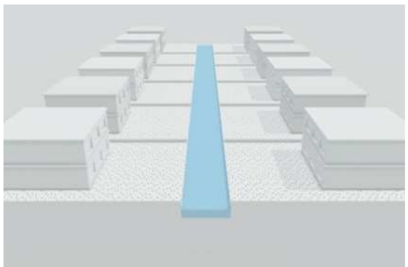


SINGEL2

sloot

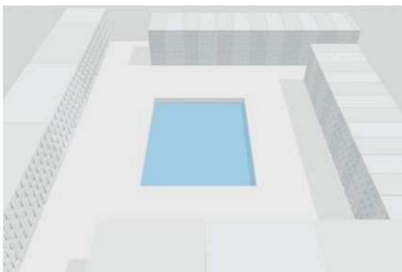


SLOOT1



SLOOT2

vijver



VIJVER1

Table 1. The REALCOOL testbeds. Images credits: Jochen Muelder

CRITERIA	REFINEMENT PRINCIPLES		
aesthetical appeal	develop the positive aesthetical qualities	visual appeal	· develop attractiveness and coherence
		openness-closure	· exploring visual connections
functional match	develop the potential to enhance pre-existing functions	activities	· taking people on/into or closer to the water
		traffic	· allowing the manoeuvring of boats
costs	develop the cost-effectiveness potential	cost-effectiveness	· developing the relevant delivered benefits
maintenance requirements	optimise maintenance requirements	cleaning	· reducing the organic material falling into water · improving the access to elements in the water
		pruning	· integrating natural growth and shapes
		watering	· choosing vegetation with low watering needs
		operational costs	· explore spontaneous maintenance solutions

Table 2. Outcomes from UC2