Developing design guidelines for climate-responsive green infrastructure

Wiebke Klemm[1], Sanda Lenzholzer[2], Adri van den Brink [3]
Wageningen University, Landscape Architecture Group,
Droevendaalsesteeg 3, 6708 PB Wageningen, the Netherlands
[1] *wiebke.Klemm@wur.nl*
[2] *sanda.lenzholzer@wur.nl*
[3] *adri.vandenbrink@wur.nl*

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1. Introduction

1.1 The need for climate-responsive green infrastructure

Designing climate-responsive urban areas is a global challenge in the context of climate change, urbanisation and existing urban heat problems. The vulnerability of humans and the urban system towards changes in temperature and precipitation patterns needs to be reduced by appropriate planning and design of urban spaces. In this context green infrastructure is an important means to alleviate urban heat and enhances human health, well-being and thermal comfort in urban areas (Lafortezza, Carrus et al. 2009, Fryd, Pauleit et al. 2011). The definition of ‘green infrastructure’ we use here refers to the broad range of vegetated spaces or vegetation elements within cities. They vary in scale from urban parks and forests to the level of gardens or street trees.

There is a growing body of specialist knowledge in the fields of urban meteorology and human biometeorology on the moderating impact of green infrastructure on urban heat and thermal discomfort: Parks are cool islands in cities on warm summer days with air temperatures about 1 K lower than in the built environment (Bowler, Buyung-Ali et al. 2010, Klemm, Heusinkveld et al. 2015a). Tree canopy shade lowers mean radiant temperature from 4 to 33 K depending on vegetation and planting parameters (Streiling and Matzarakis 2003, Armson, Rahman et al. 2013, Lee, Holst et al. 2013, Klemm, Heusinkveld et al. 2015b). In addition, green infrastructure positively influences general and momentary thermal perception: people prefer green urban spaces to water or built surroundings on warm summer days (Klemm, Heusinkveld et al. 2015a). Also street greenery, preferable at different heights like low beds, hedges and street trees, has a positive impact on pedestrians’ perceived thermal comfort (Klemm, Heusinkveld et al. 2015b).

Even though the impact of green infrastructure is well demonstrated, only few studies have drawn up guidelines based on this micrometeorological knowledge for urban designers. Recently, some guidelines for climate-responsive urban design became available (Brown 2010, Erell, Pearlmutter et al. 2011, Lenzholzer 2015), but in how far they are understood by designers and really get applied in practice is unknown. Micrometeorological results are formulated based on the knowledge/ understanding of urban climate specialists. This specific scientific knowledge often cannot easily be recognized and utilized in to site designs by landscape architects or urban planners. For example, most of the meteorological studies pay little attention to aspects such as size, distribution, lay-out and choice of vegetation to support design decisions (Fryd, Pauleit et al. 2011). Furthermore, for site designs it is hard to compromise climate knowledge with other important issues in urban and landscape design, such as requirements for the functionality of urban elements and aesthetic aspects.

Consequently, to date micrometeorological knowledge is hardly taken into account when designing green infrastructure in outdoor urban spaces. This results in sub-optimal designs of urban spaces regarding its potential to contribute to human health, well-being and thermal comfort. For efficient and sustainable design of urban outdoor spaces there is a need for implementing the available climate knowledge in urban planning and design.

1.2 Design guidelines as a bridge between climate knowledge and urban planning

The gap between climate knowledge and urban planning and design has been described earlier (Eliasson 2000, Lenzholzer 2010). It is not solely a challenge for these disciplines but can be seen as a part of the more general ‘utility gap’ between science and practice (Kantrowitz 1985, Friedmann 1987, Nassauer and Opdam 2008). To bridge this gap Nassauer and Opdam (2008) argued for collaborative, transdisciplinary approaches by scientists and practitioners, and for designing as being a part of ‘knowledge innovation’. Within the discipline of landscape architecture Brown and Corry (2011, pag. 328) promoted evidence-based landscape architecture. They call for more “scholarly information that will inform decision-making and communicate it to practitioners [being landscape architect] in a way that can be readily applied.” Also Eliasson points out the necessity to develop amongst others “tools [...] suitable for urban planners” (Eliasson 2000, pag.41). Then the question remains how to develop ‘suitable tools’, design recommendations or design guidelines of climate knowledge for the disciplines who shape urban environments? In the field of landscape architecture little has been written about what a design guideline is or how to develop it based on scientific evidence. This leaves room for steering an own course in how to develop scientifically based design guidelines for climate responsive green infrastructure.

1.3 Objective and research questions

This study aims at generating design guidelines for climate-responsive green infrastructure, being urban parks and street greenery. For this purpose, we drew up the following research questions: What are scientifically based design guidelines for climate responsive green infrastructure in moderate climates and how can they be derived from urban climate knowledge? This paper introduces the methodological approach to generate design guidelines.

In order to impact urban design, we state that design guidelines must be comprehensible, applicable and feasible. This set of criteria is based on Nassauer et al., who concluded that the effectiveness of empirical evidence suffers when "scientific tools [guidelines] are considered too complex, too prescriptive, too demanding of resources, or not flexible enough to support place-specific decisions" (Nassauer and Opdam 2008, pag 634). Consequently, we put the set of criteria into operation:

- *Comprehensibility* is related to clarity and intelligibility of the design guidelines; are designers with their specialised knowledge able to understand the meaning and content of the guidelines in order to apply them? Are the guidelines not considered too complex?
- *Applicability* is related to the usefulness of the design guidelines; are designers with their specialised knowledge able to easily, flexibly implement the design guidelines in specific site situations? Are the guidelines not considered too prescriptive or not flexible enough?
- *Feasibility* is related to workability of the design guidelines; are the site specific conditions suitable for the implementation of the design guideline? Are the guidelines not considered too demanding of resources?

2. Method

The general approach of this study is based on the research of Lenzholzer (2010) that aimed at generating design guidelines for thermally comfortable urban squares. Her research combined research on and for design as well as research through designing to create usable design guidelines. In our study we focussed on research for and through designing. An extensive research for design phase, the collection of empirical data (Klemm, Heusinkveld et al. 2015a, Klemm, Heusinkveld et al. 2015b), has been accomplished and yielded preliminary evidence-based design guidelines (Brown and Corry 2011). In order to fine-tune these preliminary design guidelines for optimal use, we involved practical knowledge from the disciplines of landscape architecture and urban design (Nassauer and Opdam 2008, Deming and Swaffield 2011) in a 'Research through Designing' (RTD) approach (Lenzholzer, Duchhart et al. 2013). The latter forms the focus of this paper.

2.1 'Research for and through Designing'

Our RTD is thus based on earlier scientific microclimate studies in moderate climates (Fig. 1). Those studies investigated the physical and psychological impact of urban parks and street greenery on thermal comfort in urban environments. They consisted of micrometeorological measurements and interviews with pedestrians on warm summer days in 2012 the cities of Utrecht, Arnhem and Rotterdam (Klemm, Heusinkveld et al. 2015a, Klemm, Heusinkveld et al. 2015b) and from observations combined with interviews in parks in the city of Utrecht and Wageningen in 2013, the Netherlands. As those studies were conducted in order to serve urban planners and landscape architects in their future design decisions, this approach can be described as research for design (Lenzholzer, Duchhart et al. 2013).

Already in the beginning of the design process, we got aware of the importance of how to communicate this scientific results to designers. Initially we tested the understanding of the scientific results, being purely qualitative and quantitative empirical findings similar to highlights in a scientific paper, with students. An example was "10% tree cover in a street lowers mean radiant temperature about 1 K." (Klemm, Heusinkveld et al. 2015b). It appeared that students were not able to link this kind of data to their design assignments. Therefore, we put the scientific findings into a wider context (tree cover creates shade and thus can improve thermal comfort) and linked it with spatial and functional aspects (thermal comfort in wide streets). Consequently, the finding above was adjusted into "Tree canopies are means to create shade in street canyons with high radiation fluxes. To improve thermal comfort for pedestrians implement trees with large canopy covers in streets with high solar radiation."

Likewise we translated our scientific results (Klemm, Heusinkveld et al. 2015a, Klemm, Heusinkveld et al. 2015b) into nine preliminary design guidelines (see appendix 1). In order to clarify intentions for implementation the preliminary guidelines were completed with aspects of special attention (do's and don'ts). Those aspects regard, for example, vegetation characteristics or planting circumstances and were derived from extensive dialogues with professional and academic stakeholders. After having finished the set of nine preliminary design guidelines, they had to be tested and fine-tuned with practical knowledge of urban designers with RTD, thus with active employment of designing in the research process.

But what actually is RTD? In the research field of landscape architecture, designing can be a method to generate new knowledge (Nassauer and Opdam 2008, Steenbergen, Meeks et al. 2008, Nijhuis and Bobbink 2012, van den Brink and Bruns 2012, Lenzholzer, Duchhart et al. 2013). This method, was referred to as 'research through/as or by design', but we will use the more precise term 'Research Through Designing' (RTD) as Lenzholzer et al. (Lenzholzer, Duchhart et al. 2013) suggested. In this term the active form of the verb 'designing' indicates the active employment of designing within the research process. The RTD approach can be used to generate design guidelines or develop them further (Frayling 1993, Lenzholzer, Duchhart et al. 2013).

The RTD approach in our study comprises a design process, the direct application of the preliminary design guidelines, an assessment of the design process and products and adjustment/ improvement of the preliminary design guidelines towards final design guidelines. The design process and the methods to assess the results are explained in the following chapters.

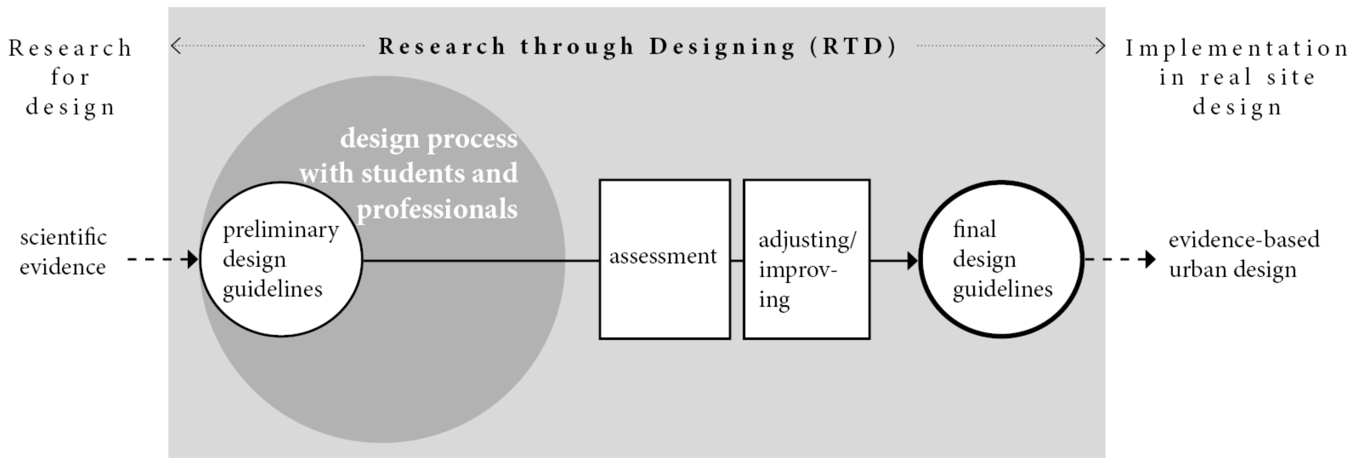

Fig. 1: RTD approach to derive evidence-based design guidelines

2.2 Design process

In the design process the preliminary design guidelines were implemented actively in two separate design studios. For testing and fine-tuning the preliminary guidelines we choose to have two different groups of participants, one being landscape architecture students (Atelier 2014), the other being professional landscape architects and urban designers (Green force workshop). In this way we expected to involve innovative ideas and creativity of students' as well as the practical knowledge and long-term experience by professional urban designers in the process of improving the preliminary design guidelines. Furthermore, both groups represent the end users who should apply the design guidelines in their practical work.

The **Atelier 2014** was a joint design studio with 4th year students of the Master in Landscape Architecture and Land Use Planning at Wageningen University, the Netherlands (Etteger, Haan et al. 2014). The studio took place from 17th of March to 9th of May 2014. The topic of the design studio was improving the green-blue infrastructure in and around the city of Utrecht and its contribution to the ecological, recreational, hydrological and microclimatic functioning of the city. The studio included a group phase (first 8 weeks) and an individual phase (last 4 weeks). The design process of the study at hand focusses the individual phase of 24 participating landscape architecture students. In this phase students individually chose a site specific project through which they developed a concrete design contributing to the green-blue network of Utrecht. The choice of the specific location and assignments was based on the groups phase and the students' individual preferences. Consequently, the priorities of microclimatic improvement in the design assignments differed. During their individual work, students were supervised on weekly basis. Every student had to deliver a report, three posters and give short presentation in the end.

The studio **'Green force' initiated by Aorta 2014** was a two day transdisciplinary design workshop initiated by the Centre of Architecture in Utrecht with professional landscape architects, urban designers and other stakeholders from the municipality (Heide, Meijer et al. 2014). The workshops took place on 19th and 27th of May 2014. The topic of the workshops was to investigate spatial design principles for a more green and more healthy city of Utrecht and the implications for involved parties/ stakeholders and financing. Three neighbourhoods of Utrecht with different spatial and socio-economic characteristics had been chosen as study areas in advance. The two days' workshop included a field trip, lectures and design studios, in which participants actively worked out the assignment. The studios were organised in two groups of 10 and 11 persons, respectively. In each group there were three urban designers, being landscape architects or urban planners. Other participants came from varying disciplines (e.g. economy, ecology, health) and were stakeholders from the municipality. Every group was guided by a professional urban designer. The two groups had to deliver sketches and illustrations produced during the workshop and give a final presentation.

Based on the topics of the design studios it is apparent that in design improving the microclimate was just one of the various design challenges that the participant had to address. In both studios the participants were free in deciding to what extent improving the microclimate would play a role in their final design. This to us seems a representative approach for real design and decision making processes.

Participants of both studios were unexperienced in climate-responsive urban design. To introduce the topic we gave lectures in the beginning of both studios. Here we explained scientific relevance of climate-responsive urban design (for example climate change and adaptation strategies) as well as the set-up and results of the finished scientific studies. In the end we presented the preliminary design guidelines. Additionally, all participants received handouts with the preliminary design guidelines and aspects of special attention. During the design studios there were possibilities to obtain additional advice by a microclimate expert.

In both design studios, the main researcher of this study had the role of 'external microclimate expert'. That encompassed a limited advising role in the organisation of the studios, but no active participation in the design processes. Major tasks were giving introduction lectures and supervision/ advising. Furthermore, the researcher also observed conversations, the design process and made notes.

2.3 Assessment process

The research design of the assessment process comprises plan analyses of the design results, observations of the design processes, and conducting surveys with studio participants about their experiences during the design process. In all methods the focus is on assessing comprehensibility, applicability and feasibility of the design guidelines. The use of three different methods enables us triangulate outcomes (Boeije 2010, Deming and Swaffield 2011) and gain a varied view on the implementation of the design guidelines (process) and the results (product) of the design process. Based on the assessment outcomes the preliminary design guidelines will be evaluate and adjusted into final design guidelines. This assessment process is currently running.

Plan analyses were conducted based on the final products of the design studios. In the case of the students' design studio, the results are 24 individual student reports. Here, we focussed on the chapters describing the analysis and the final site design. In case of the Aorta workshops, the raw final materials were sketches presented in the final presentations and video recordings of the final presentations. Based on photographs of the sketches and the minutes from the presentation we produced two accounts, one for each group. Both students' reports and accounts consist of visual material, such as maps, cross-sections and schematic illustrations, and textual material, which explains and substantiates design decisions. Based on deductive/inductive coding we analysed the plans using Atlas.TI. To increase reliability, the coding will randomly be checked by multiple researchers.

Observations, including taking notes of the design processes in a logbook, were carried out during the design processes. We conducted observations either during the weekly tutoring moments in case of the students' design studio and during the whole design studio in each of the two groups in case of the Aorta workshops with professionals. Data analysis includes deductive/inductive coding (Atlas.TI) related to comprehensibility, applicability and feasibility of design guidelines of the textual accounts of observations.

Surveys in the form of semi-structured questionnaires were taken with all participants, both students and professional urban designers, by the end of the design studios. In the questionnaire participants were asked to evaluate the criteria of comprehension, applicability and feasibility based on statements for each of the nine preliminary design guidelines in a five-point Likert-scale from strongly disagree to strongly agree. Additional, participants were asked to give suggestions for improvement or other explanation to their response in an open question. Questionnaire results will be analysed using descriptive statistics (Excel) and inductive coding (Atlas.TI).

Finally, the results of both groups will be combined and the research methods will be triangulated to gain integrated insights in the comprehension, applicability and feasibility of the preliminary design guidelines. These insights will then be used to adjust the preliminary into the final design guidelines.

3. Discussion and conclusions

The analysis of the collected data is ongoing. So far the study showed that participants were aware of the relevance to include climate-responsive green infrastructure in their designs. Generally, they knew about moderating effects of urban green. However, applying climate-responsive green in site specific designs seemed to be challenging. It required subjecting the guidelines to other functional issues, for example limited space due to infrastructural needs like car parking or underground infrastructure. In those cases site specific solutions had to be found to still implement greenery. Another challenge seemed analysing microclimatic circumstances of a specific site. The quality of microclimatic analyses varied which partly resulted in scarce analytic microclimatic foundation of the designs.

Even though it is not finished yet, this study seems promising in translating scientific micrometeorological evidence into suitable tools for urban designers. It helps to bridge the gap between climate knowledge and urban design (Eliasson 2000). The refined design guidelines will offer scientifically based utilizable knowledge for climate-responsive designs of green infrastructure in moderate climates.

This study, furthermore, shows the added value of combining scientific evidence and practical knowledge in active design processes to develop design guidelines. The derived design guidelines are not only evidence based but also effective in terms of comprehensibility, applicability and feasibility. Eventually, the application of design guidelines for climate-responsive green infrastructure in future urban design projects will result in more healthy and thermally comfortable outdoor urban spaces.

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Appendix 1 – Preliminary design guidelines as implemented in the design studios

CITY 1 People generally perceive urban green spaces as thermally comfortable and make use of green spaces on warm summer days. To improve thermal comfort and use of outdoor open spaces on warm summer days **(1) preserve and maintain, (2) improve qualities within or expand existing green spaces and (3) develop new green spaces in cities. Here, green spaces but also the sum of small scale green elements contribute to improved thermal comfort in cities.** 2 People without private outdoor spaces as well as elderly people (and families with young children) make more use of green spaces in the direct surrounding of their home. To enhance the possibility of those groups to use outdoor open spaces on warm summer days **guarantee the presence of public green spaces in neighbourhoods without or hardly private outdoor spaces and in neighbourhoods in which inhabitants mainly are elderly people (and young children).** 3 The green fraction of the built surrounding on the wind side of an urban are influences thermal conditions within that urban area. Therefore, green elements and green spaces on all scale levels (street, park, city) in the city contribute to mitigate heat. To improve the urban microclimate during summertime p**reserve and whenever possible increase the green fraction, (including private and public green elements and green spaces) on the wind side of the prevailing summer wind direction.** **PARK** 1 People in parks adapt to thermal conditions to ensure their (momentary) thermal comfort. To enhance people's choice in which places they would like to sit and sojourn c**reate diversities of microclimates combined with park furniture (benches both in sun and shade) in parks.** 2 People behave proactive to create their own thermally comfortable microclimates (bringing their own parasols, elements to sit etc.). T**o** facilitate individual thermal adaptation **create flexible and multi-functional spaces in parks.** 3 Edges between sun and shade are popular places to stay in parks, as people easily are able to adapt to diverse thermal conditions. To facilitate individual thermal adaptation in parks c**reate gradients/ borders of open areas and shading elements where sun and shade are provided in close vicinity and alternation.** **STREET** 1 Tree canopies are means to create shade in street canyons with high radiation fluxes. To improve thermal comfort for pedestrians **implement trees with large canopy covers in streets with high solar radiation**. 2 People adapt to thermal conditions to ensure their (momentary) thermal comfort. To enhance people's choice in which places they would like to walk **create diversities of microclimates (sun/shade) in street canyons.** 3 People's perceived thermal comfort in streets with green elements is better than in streets without green elements. The more green elements people perceive on different levels: low (grass, flowers), medium (hedges, shrubs) and high (tree canopies, green facades) the better they evaluate their thermal comfort. Furthermore, aesthetical appreciation of street greenery enhances perceived thermal comfort. To improve perceived thermal comfort of pedestrians **implement aesthetic (meaningful, beautiful) green elements in street canyons, preferably at various heights (including public and private spaces).**	**Aspects of special attention** Shadow needed the most during periods with highest radiation (12:00 - 16:00) Deciduous trees are preferred (shade during summer/ radiation during winter) Species resistant against heat, drought, cold and salt (for icy roads) Good planting circumstances (incl. sufficient space for the root system, high quality ground, sufficient irrigation during summertime) Effective implementation of street trees (instead of trees everywhere) depending on specific site characteristics (H/W ratio, orientation toward sun) Avoid 'tunnel effect' in streets with heavy traffic by creating space for wind circulation between the tree canopies

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