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Climate-responsive landscape architecture design education

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ABSTRACT

There is compelling evidence that Earth's climate is changing, in most cases becoming warmer. This effect is exacerbated in urban environments by the growth of urban heat islands. These two processes can have far-reaching effects on human thermal comfort and health. Landscape architecture is well positioned to ameliorate these effects through planning and site design, but only if the designer understands how an urban environment creates microclimates. In order to prepare our students for the climate challenges they will face in future urban planning and design practice, we have introduced climate-responsive design classes into the curricula of two schools of landscape architecture, one in Wageningen, The Netherlands and the other in Guelph, Canada. In this article we describe the methods that we used to teach climate-responsive design by integrating scientific information into the creative design process. The method consisted of three main steps. First students accumulated and summarized climate knowledge at the appropriate scales. This information was used to analyze a study site and identify climate-related problems. The final step was to use this knowledge as a basis for generating design solutions and testing them for their climate-appropriateness. These courses prepare future professionals to ameliorate the effects of climate change and urban heat island intensification and create living environments that are thermally comfortable and healthy.

1. Introduction

Measurements over the past few decades have identified a trend where the Earth's climate is gradually getting warmer. There is also evidence of an ongoing global migration of population from rural to urban areas with more than half of the world's population now living in cities. In cities, urban heat islands (UHI) emerge where the centers of cities are substantially warmer than the surrounding countryside. These two warming trends, one global and one more local, are likely to have a substantial and negative effect on the thermal comfort (*e.g.* Brown, 2011), health (*e.g.* Vanos et al., 2012), and well-being of many urban dwellers. Apart from that, this also leads to increasing use of air conditioners and thus to even more CO_2 emissions and worsening of urban heat problems. Clearly, this trend needs to be changed and the need to adjust our urban environments in response to climate and, more recently to climate change, has been broadly discussed (*e.g.* Eliasson, 2000; Gill et al., 2007; Lazar and Podesser, 1999; Scherer et al., 1999; Smith and Levermore, 2008).

Landscape architecture is well positioned to ameliorate these effects through climate-appropriate landscape, urban planning and site design, as it is clear that the orientation of buildings, composition and color of surface materials, and types and locations of vegetation have major effects on the urban heat islands and on microclimates. These interventions can improve outdoor climate and facilitate longer outdoor sojourn. They can also contribute to a better indoor climate and thus lower use of heating or air conditioners and hence CO_2 emissions. Such climate adaptation can be influenced at various scales (*e.g.* Lindley et al., 2006; Ren et al., 2012; Shimoda, 2003) and it is consequently important to address climate responsive design at different scales as well. This ranges from adapting whole metropolitan areas to climate challenges to improving small places where individual people spend time outdoors.

However, without an understanding of the processes by which urban and landscape elements affect climate, and how microclimate influences the thermal comfort of people, designs can create inadvertent microclimate modifications that can make the situation worse. Although there is a basic body of design knowledge on urban climate and microclimate (Boutet, 1987; Brown and Gillespie, 1995; Brown, 2010; Lenzholzer and Koh, 2010; Lenzholzer, 2012; Municipality of Stuttgart, 2008; Robinette and McClennon, 1983; Santamouris, 2001), climate-responsive design has been addressed

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only superficially in landscape architecture teaching. Clearly this has to change if we hope to have a positive effect on mitigating the warming urban climates of the world.

In the future we likely face great challenges to rebuild or retrofit cities and landscapes for the expected, and unexpected, effects of climate change. Students need to be prepared for these challenges and to apply their knowledge of climate-responsive design in their professional practice.

The challenges that climate change poses to landscape architecture ask for a very careful and deliberate way of designing landscape and urban environments that is based on well-founded arguments, essentially research-based design (Brown and Corry, 2011), and during the design process a cyclical testing of designs on their climate effects. These criteria are reflected in the teaching methods we used in our courses, which we explain in more detail in the following.

2. Methods

In both schools, we used the same basic didactic literature to inspire our design studio classes on 'real world' learning. But supporting our studios with didactic scholarly literature on climate-responsive landscape architectural design was a greater challenge. Basically we were unable to find didactic examples of such classes in the literature. This paucity of exemplary approaches led us to use the existing scarce information from architecture and building engineering to guide the setup of courses on climate-responsive design.

2.1. Problem-based learning for realistic and relevant design results

Both schools have a clear orientation to practice-oriented learning and offer design classes that have a close relation with the 'real world'. This is inspired by the learner-centered approach in which students and their experience of the world and its problems are pivotal (Bodner, 1986; Newmaster et al., 2006). It has been shown that learning progress is stronger when students see problems themselves – either by their own experience or when the problems are presented by 'real people' or they deal with 'real places' so that the 'relevance' of the problems is evident to them. When students are then provided with appropriate instruments to tackle the problems they show the best learning motivation and results (Kember et al., 2008). For this reason we offer 'real world cases' in our design classes. This requires that students deal with real sites and often also with real stakeholders with whom they communicate their research and design results.

2.2. Searching for design methods for climate responsive design

As indicated above, due to that lack of didactic literature in landscape architecture on climate responsive design, we relied on

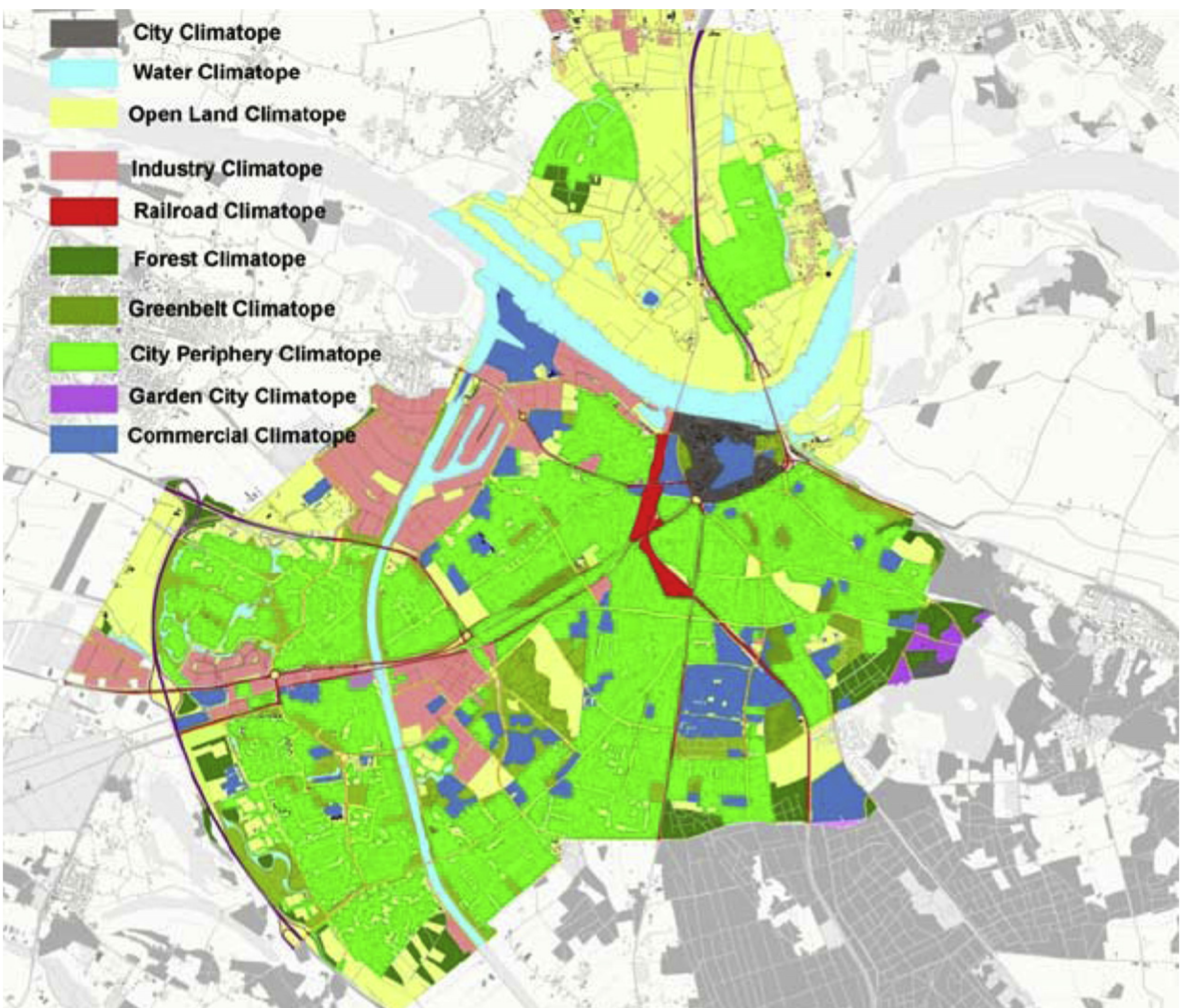

Fig. 1. Climatope map of the city of Nijmegen (Shuangyu Han, Yinan Ji).

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teaching methods that were used by other disciplines. Scholars with experience in bioclimatic architecture (Evans and de Schiller, 1990; De Schiller and Evans, 1996; Yannas, 2004, 2005) reported about their teaching methods and the steps taken in their design studios. Also didactic knowledge from engineering was useful such as Wisse's 'philosophy for teaching wind in the built environment' (1988) where he explained steps in design processes for wind engineering and how this can be used in urban design. All these authors' experiences share that at first a basic understanding has to be generated amongst the students about indoor/outdoor bioclimate or wind patterns. This newly acquired knowledge has then to be applied in a design process. The design alternatives that are developed in the process are also to be tested. All authors emphasize this testing phase because the impact of design interventions for climate is complex and in a real world case it would be irresponsible to not test designs as rigid as possible.

Based on those experiences of scholars in other fields we structured the climate-responsive design studios into three phases:

a) review and summarize scholarly literature on climate issues related to landscape.

This encompasses the reading of literature that is provided by the tutors for junior students or when the studio duration is very limited. For more senior students a more independent literature search is preferred.

b) analyze the region and site in terms of its effect on climate

This phase includes not only classical landscape and urban analysis, but especially the analysis of the environment and it's effects on wind patterns, sun and shade and urban heat distribution during different seasons and points of time during the day.

c) develop and test climate responsive design proposals

Different alternatives for designs are developed and tested. These tests can consist of computer simulations, but also of more qualitative 'educated guesses'. For the latter, rigid examination of the design proposals by the tutors play a crucial role.

Obviously, the tutors need to be specialists both in landscape architecture/urban design and also in the field of outdoor climate studies to be able to guide and assess student's studio work in a valid and reliable way.

We are well aware of the fact that the different steps in the design processes described above cannot always be 'dissected' in the way we discuss them in this paper. This is due the fact that design processes are mostly cyclical in nature and that these phases are thus often running parallel or are intermingled. For communication and clarity purposes, however, we discuss them separately.

In the following, we will exemplify how climate-responsive design on different scale levels was taught in the two landscape architecture schools.

3. Example urban climate analysis and design, MSc class Wageningen

In Wageningen University climate-responsive design was introduced in a 3-month design module in the MSc programme and was taught in three consecutive years with different cases each year: the Dutch cities of Arnhem, Nijmegen and Tiel. Here, the students cooperated closely with stakeholders from local

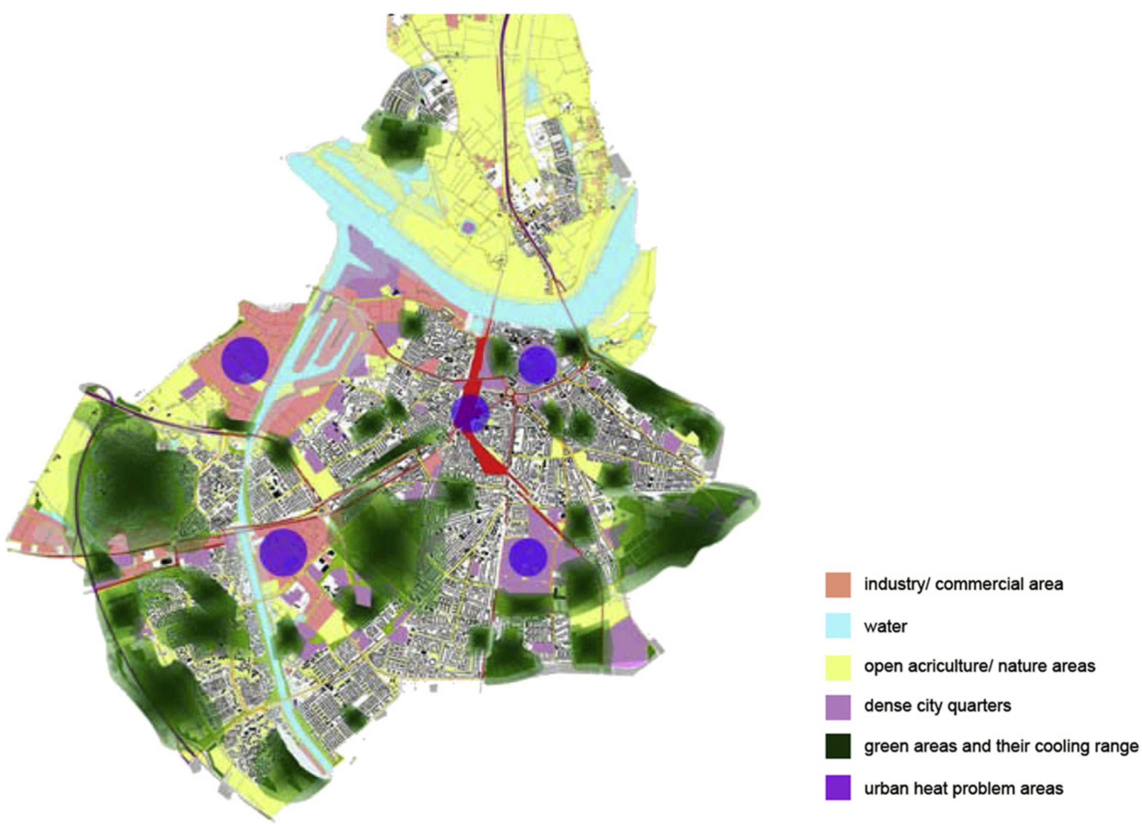

Fig. 2. Approximate reach of cooling potentials of parks and water bodies in the urban fabric of Nijmegen and heat problem spots, Nijmegen (Shuangyu Han, Yinan Ji, 2009).

municipalities. This studio followed the didactic structure described above and the design process covered scale levels from city to site level.

3.1. Acquiring basic urban climate knowledge

In the first, the 'knowledge acquisition' phase the group of students took about a month to gather scientific knowledge that could be used as design guidelines or from which design guidelines could be deduced. The literature studied encompassed the basic knowledge quoted in Section 1 and additional specific articles. Then, different groups conducted a deeper literature research. They focused on different remedy types: climate improvement with vegetation, with water and with urban topography/morphology. All this knowledge was brought together and shared as a common 'knowledge pool' that was the basis for the subsequent phases.

3.2. Urban climate analysis, large and site scale

The second phase was a qualitative urban climate analysis. This analysis formed an important bridge between understanding the scientific climate knowledge and what this means in a real world environment. Here, the students identified the problems and potentials for urban climate. Due to the lack of quantitative measurements or simulation data within the municipalities, the students used methods that they had found in the Climate Booklet for Urban Development for Stuttgart (2008). Since this did not provide ample methodological examples for this climate analysis the students were sometimes quite inventive in generating their own methods to make qualitative predictions.

The issue of urban heat complexes was analyzed with the 'climatope' method. Climatopes form – similar to biotopes – areas with certain climate characteristics, predominantly due to their land use. Densely built up city areas, commercial or industrial areas, large paved surfaces such as parking lots or railway yards, for instance, are areas that are prone to show distinct heat problems, especially at night (Fig. 1).

Cooling potentials could be identified for the direct surroundings of green and open water areas and were depicted in maps (Fig. 2), showing the approximate reach according to Yu and Hien (2006).

Cooling potentials for the city centre by nocturnal cold air streams coming downhill to the foot of hills were revealed for the city of Arnhem. Analysis of valley geometries led to the conclusion that several small valleys have the potential to carry cold air into the dense city centre where heat problems are expected (Fig. 3).

In The Netherlands wind, and especially the prevailing strong Southwesterlies, form a prominent problem. Identifying large openings in the urban fabric and landscape structures, the students depicted problem areas that can be affected by these winds. Additionally, the students analyzed wind problem areas according to the smaller scale street patterns in different neighborhoods and building morphologies. With this analysis, they identified the areas where ventilation problems may exist and areas where a higher roughness through tall buildings might bring about more turbulences. Wind can, of course, also be a relieving factor. In hot situations, the cities can induce convective winds from the surrounding open areas into the city (Fig. 4).

We concluded from the climate analysis that effective interventions should be taken on various scale levels and from this we derived 'recommendation maps' (Fig. 5) for urban planning.

As a next step, individual students zoomed in to strategic spots that had either interesting urban climate potentials or difficult problems for further analysis and design.

3.3. Design proposals, local scale

After the climate analysis of the site, the students came up with climate-responsive design proposals. The issues of heat accumulation, sun/shadow and wind effects were addressed in various alternatives of design solutions. Subsequently, these were tested on their effects. Shadow patterns of the design interventions were tested for different points in time (through Sketch Up shadow simulations). Qualitative wind field evaluations were used to identify areas where lower and higher wind speeds occur due to a new design intervention. The designs that focused on climate in the first place were then combined with other issues that were locally important, such as landscape ecology, hydrology or urban regeneration.

The integrated local designs were not only tested through simulations or 'educated guesses' by students and cross-examined by the tutors with their climate expertise, but also by external

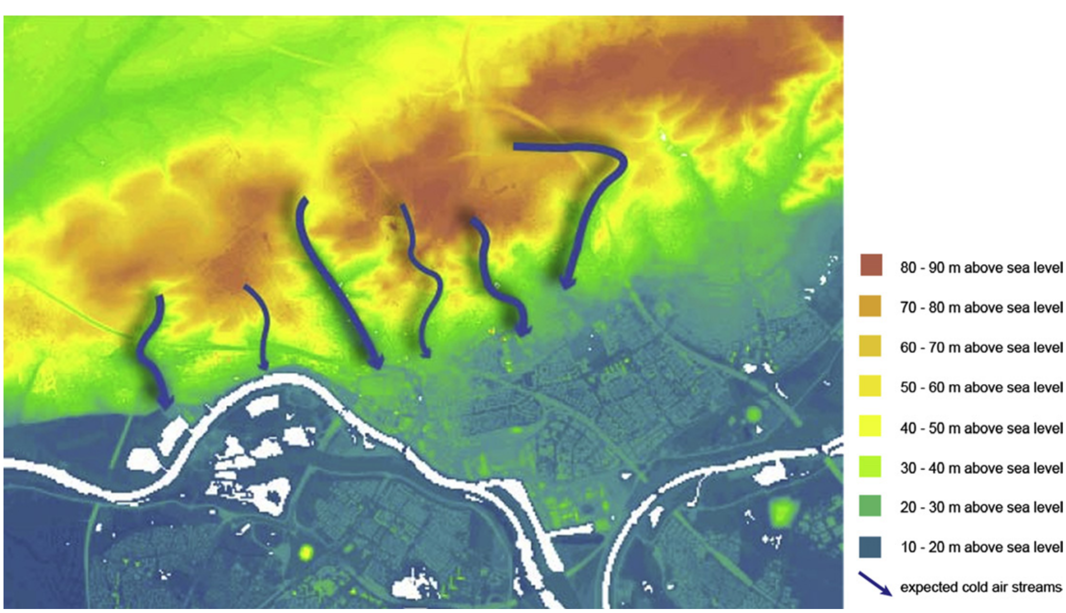

Fig. 3. Location of cooling downhill winds during summer nights in Arnhem (Jana Myskova).

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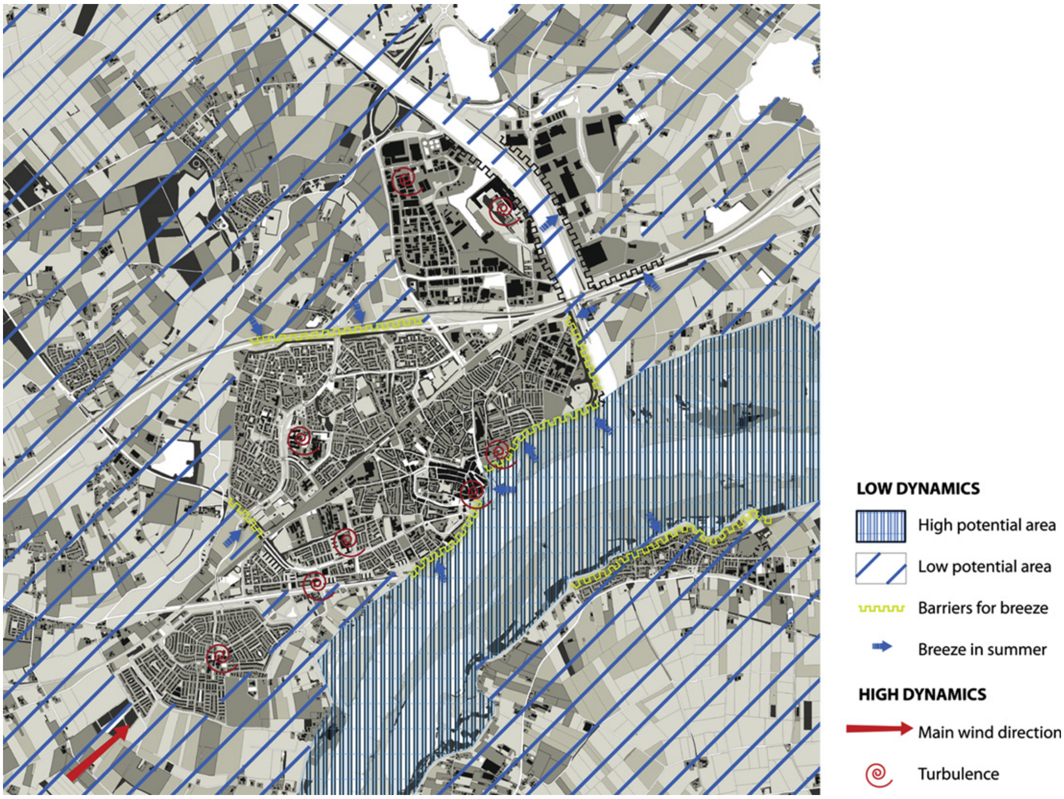

Fig. 4. Wind problems and convective ventilation potentials for Tiel (Darius Reznek).

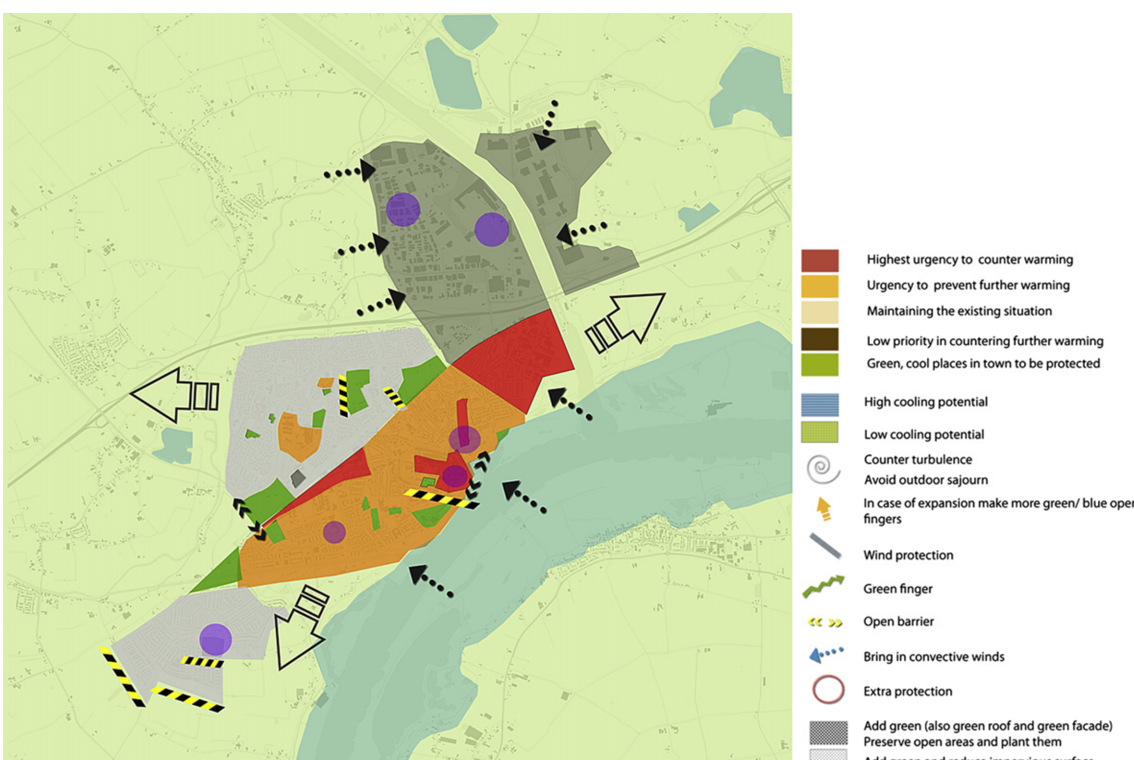

Fig. 5. Recommendations for climate responsive urban planning for Tiel. (Diana Lukjanska).

specialists from urban meteorology. This enhanced the scientific reliability of the design solutions.

One interesting example of a local design is the proposal for the English landscape park Sonsbeek in Arnhem, where potential cold air generation areas as well as many cold air stream channels exist. But due to the dense planting patterns in this monumental park this cold air system is hampered. Therefore, a student introduced a radical redesign of this park in which the patterns of tree planting and open areas follows the logics of cold air streams and generates entirely new spatial patterns (Fig. 6).

It also lead to a radical proposal to open cold air corridors into the city centre which required to open a new passage under the massive railway dike that separates the centre and the park (Figs. 7 and 8).

Another original example is a project in which natural processes of wind climate and groundwater level changes are used in climate responsive site design. For the area of Latenstein in Tiel, problems with uncomfortable southwesterly wind and thus an unpleasant sojourn quality in the outdoor spaces were identified for the seasons of spring and autumn, caused by too much wind. At the same time, the area has very high groundwater levels during these seasons. A student has smartly made use of both natural dynamics and projected a system of wind screening poles that rise out of the ground powered by the rising groundwater in spring and autumn. In summer, when ground water levels are low and sufficient ventilation outdoors is needed, the poles are sunken underground. This dynamic can create very playful patterns that not only generate comfortable sitting places, but also reveal the hidden movements of groundwater levels and together with special light effects, lively nightscapes (Fig. 9).

4. Example microclimate courses at the University of Guelph

At the University of Guelph two courses were used in the study. One was a second-year undergraduate course in the Bachelor of Landscape Architecture program, and the other was a first-year course in the Master of Landscape Architecture program. Both courses focused on learning first about the various biological, physical, social, and cultural elements in the landscape, and then learning about how to use this to inform design. In keeping with Kember et al. (2008) students were given a choice between two design projects. One was to design a neighborhood that would be both energy efficient and would provide outdoor spaces that would be thermally comfortable for as much of the year as possible. The other project was to identify a microclimatically-appropriate location for a sitting area on the Guelph campus, and then design the most thermally-comfortable microclimate possible so that people could use the area throughout the year. The course design followed the microclimatic design process proposed by Brown (2010) and was focused on mitigating climate at a micro to meso scale.

4.1. Acquiring and analyzing urban climate information

In the classes at Guelph University, the phases of knowledge acquisition and climate analysis of the region and site ran parallel and consequently we describe them together in this section.

In the knowledge acquisition stage teams of students took about a week to gather basic information on the climate of their site and on appropriate climate-responsive precedents from similar climatic regions around the world. Climate *normals* of air temperature, humidity, wind, and radiation were acquired from a nearby weather station and put into tabular and graphic format. Students were encouraged to consider *conditional climatology analyses* such

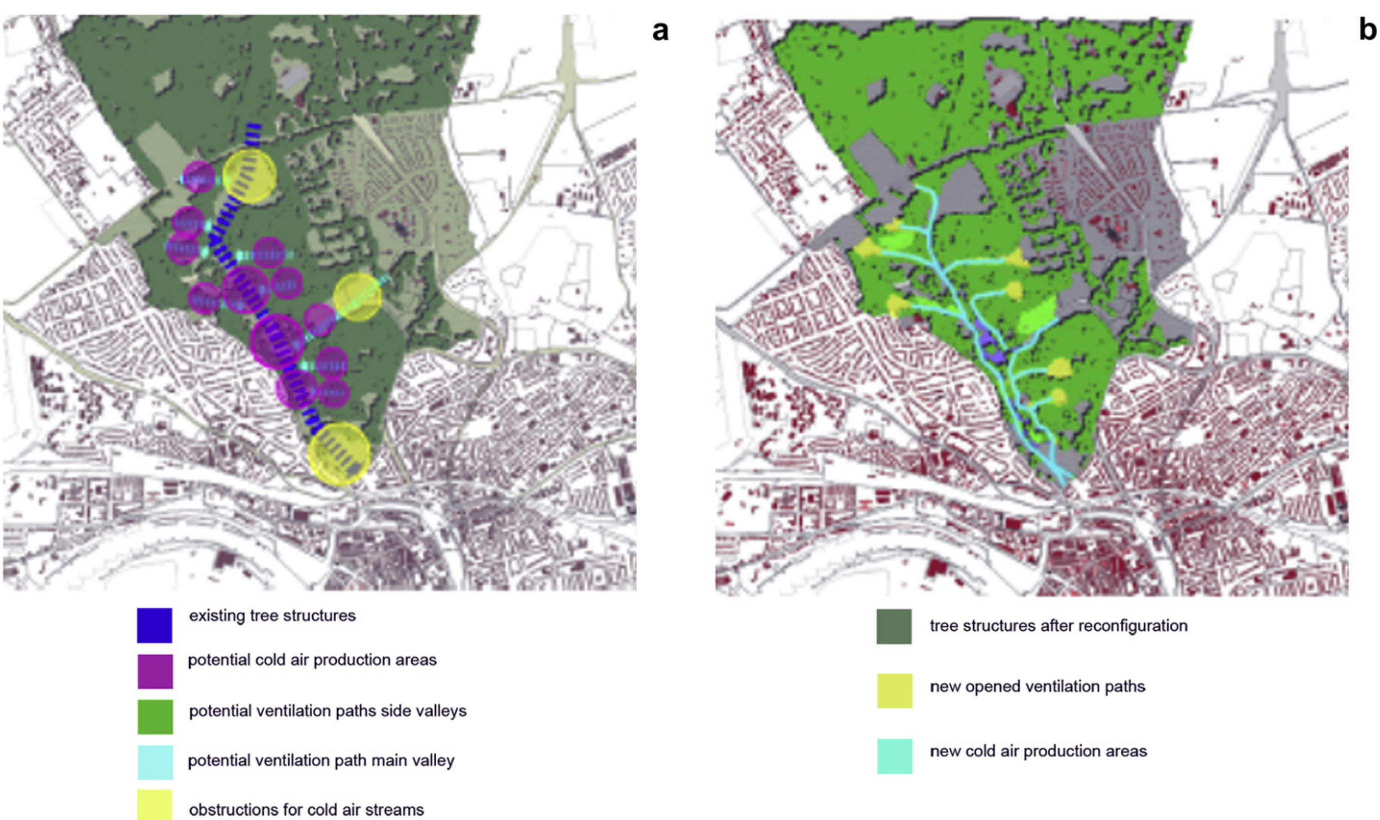

Fig. 6. a, b analysis of Sonsbeek park with its potential fresh air corridors and proposal for change of planting structure (Wen Jiang).

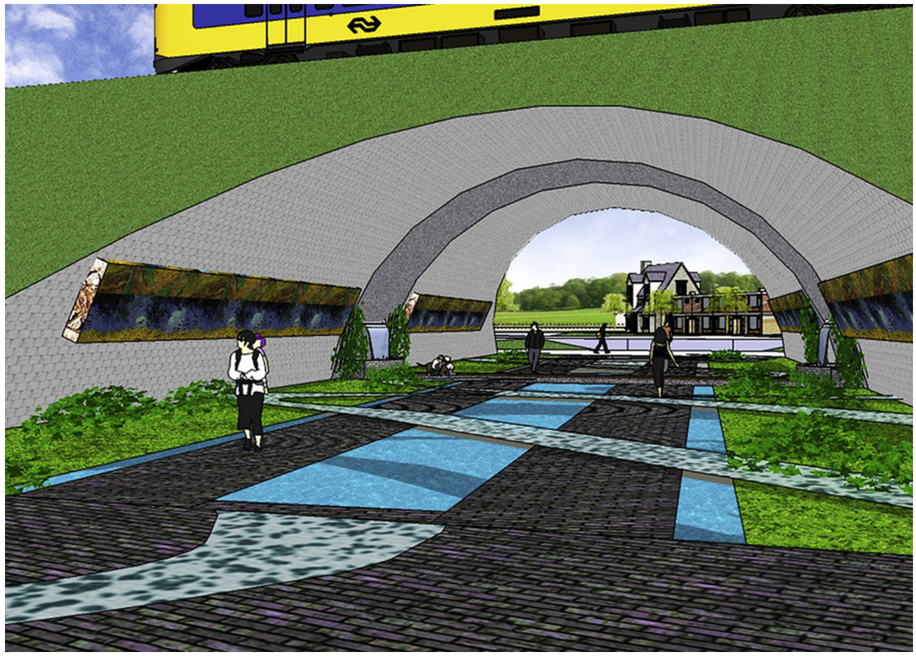

Fig. 7. Impression of the new passage under the railway dike connecting the city centre with Sonsbeek park (Wen Jiang, 2008).

as wind roses that identified the percentage of the time the wind blows from each direction during specific weather conditions. For example, wind conditions during January days can differ significantly (Fig. 10a,b).

This information would be used by the students later when they were determining where to locate a windbreak so as to make areas less windy and more thermally comfortable in winter, or where to locate a snow fence to capture snow away from roads or entrances to buildings. Summertime winds were similarly split, with Fig. 10c illustrating all August winds while Fig. 10d is when the sun was shining and it could be expected to be particularly hot.

The second step was to identify the climatic region of their study site using the Koppen climate system. In this case their region was Dfa, or humid continental climate with a hot summer. They then searched the world for other Dfa climate regions, which they found in areas such as northeastern USA, Western Europe, and northern Japan. They studied the literature for precedents of successful climate-responsive designs in these regions. Designs that were constructed in concert with the climate were then analyzed to identify climate-responsive characteristics. This provided the students with a palette of climate-modifying landscape elements. For example, Frank Lloyd Wright homes and landscapes in the USA were found to modify the solar radiation through the use of long overhangs oriented toward the south. These provided shady outdoor spaces in hot summer months, but solar input in winter when the sun was low. A similar pattern was found in Japan where the dry landscape gardens are oriented so that there is a long overhang to the south of the dojo, providing shade in summer but allowing solar access in winter.

The third step was to conduct a site assessment that identified and mapped the characteristics of the landscape that affect microclimate. Slope, aspect, vegetation type and density, moisture regimes, etc. were mapped and analyzed in terms of what kinds of microclimates they would produce. They considered the site at various scales, from very coarse to very fine. For the urban design project the students considered their site of approximately 200ha in terms of being self-sufficient in energy. They identified hilltops

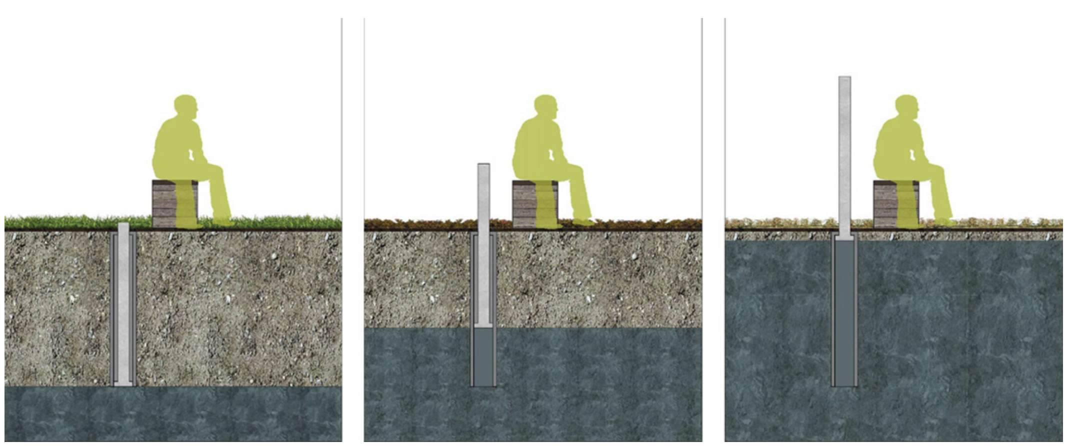

Fig. 8. System of groundwater driven windscreen poles – low position in summer (left), intermediate position (middle) and high position in spring and autumn (right) (Darius Reznek).

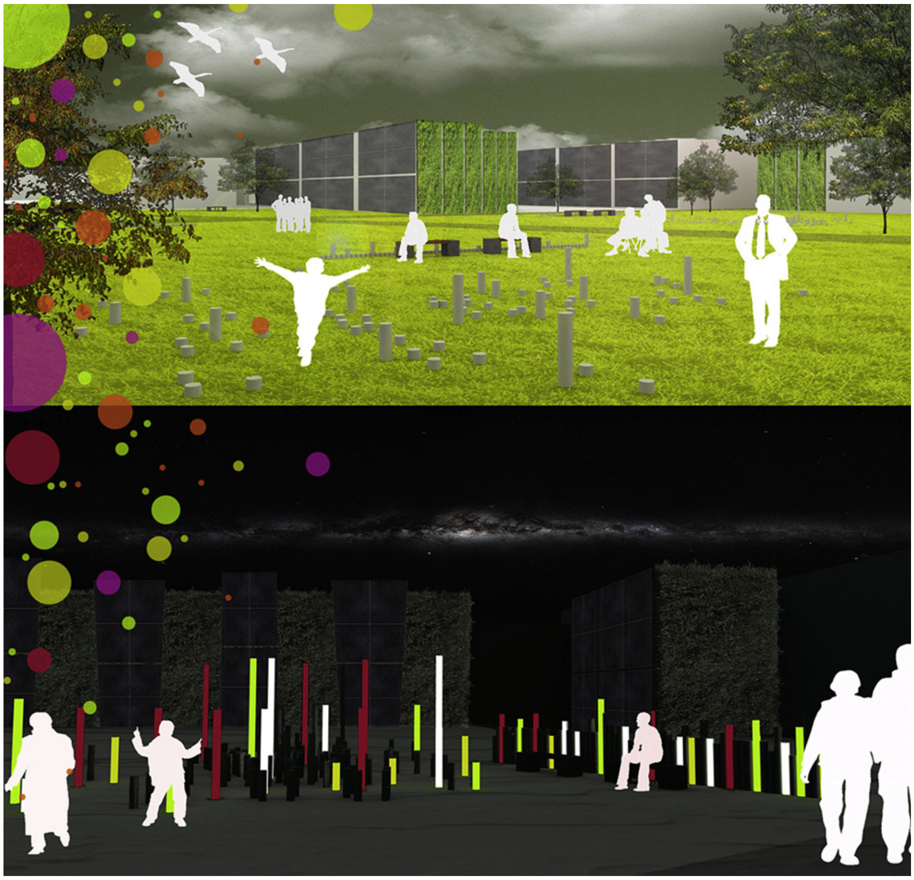

Fig. 9. 3D artist impression of the playful patters of the windscreen poles in summer (above) and spring/autumn at night (below) in the outdoor spaces of Latenstein (Darius Reznek, 2011).

where the wind would be strongest as potential locations for wind energy generation, and considered south-facing slopes as having the most potential for solar energy.

For the seating area project the students analyzed the campus to identify locations that already had favorable microclimates. They used SketchUp to build the campus buildings, then turned on the solar simulation feature and developed shadow patterns for critical times (Fig. 11a and b).

They considered the time of year (September to April, when most students are on campus) and the time of day (mid-morning coffee time, mid-day lunch, and mid-afternoon coffee) for their simulations, identifying the sunniest locations. They analyzed the conditional wind roses and found that on sunny fall, winter, and spring days that most of the wind comes from the southwest to northwest quarter of the compass. They then assessed their sunny locations in terms of the amount of wind they would receive and whether or not this wind could be reduced through the use of windbreaks. The most favorable sites were those that were sunny during the critical times, and that were either shielded from the wind or could be shielded through the addition of windbreaks.

4.2. Designing with urban climate information

One potential criticism of microclimatic design is that it might become too automatic and focused on solving the problem rather than being creative. To counter this we used creative exercises to encourage students to explore a wide range of effects that they might be able to achieve in their designs. Each team generated many creative and interesting ideas and concepts inspired by their understanding of climate. Design solutions addressed microclimate-modifying issue ranging from slope and aspect through placement of a steep berm (Fig. 12a above left), installation of a solar-powered water feature (Fig. 12b above right), and appropriate locations for Cedars, Aspens, and native grasses (Fig. 12c, trees to remain shown in dashed outlines, below left), and movable, heat-absorbent furniture and on a pea gravel surface (Fig. 12d, below right).

At this point, though, students did not know whether or not these designs would achieve their objective of providing thermally comfortable outdoor areas through the combination of wind, shadow and evaporative cooling. So testing was undertaken in the form of computer modeling and simulation of human thermal comfort. The testing phase involved the students using an interactive version of the COMFA (Brown and Gillespie, 1995) simulation program to assess the thermal comfort characteristics of potential sites. They used input variables about potential users such as typical clothing, and determined thermal comfort levels if nothing was done to the site. They then modified the site with the goal of making it more thermally comfortable, and tested their interventions through the COMFA model. This allowed them to optimize the level of comfort and the amount of time that people would be comfortable in the sitting area.

There was some unexpected collateral learning that took place at various stages in the process, particularly when some students investigated the connection between site and climate in more detailed ways. For example, one group of students explored the conditional wind conditions of a site in an attempt to create an

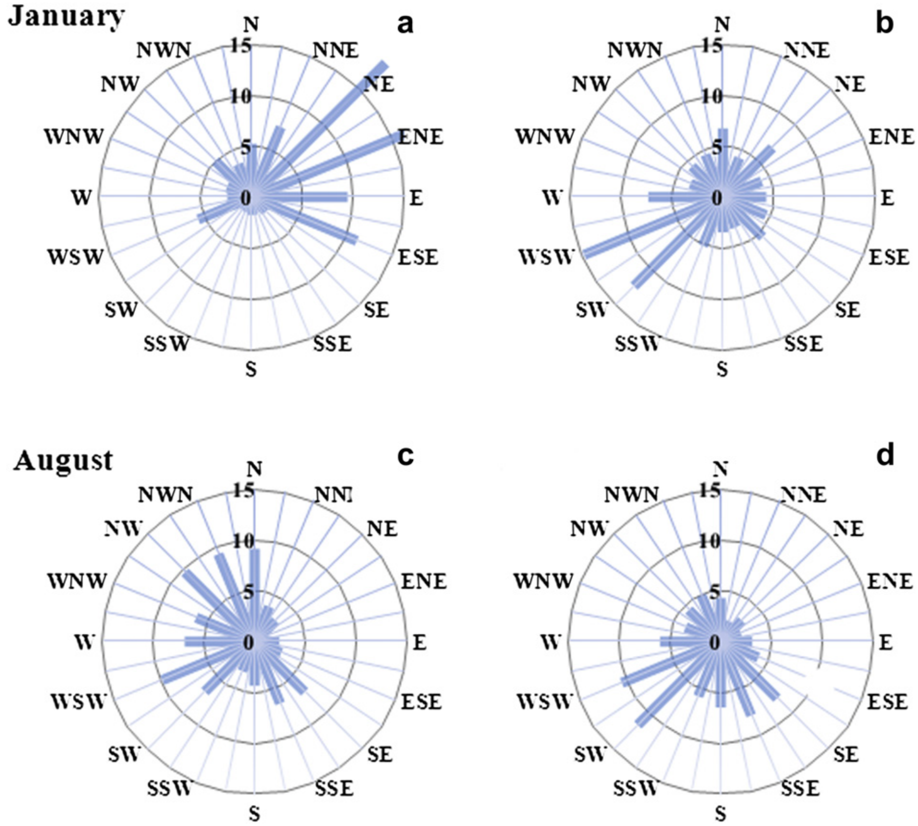

Fig. 10. a–d wind rose diagrams near Guelph, Canada. Percentage of the time that wind blows from each direction, during January when the sun was shining (above left), and when it was snowing heavily (above right) and percentage of time that wind blows from each direction during August in total (below left) and when the sun was shining (below right).

outdoor environment that would be thermally comfortable in mid-winter. They did this by considering the directions that winds typically blow on clear days so that they could design sun pockets where people would be in the sun and protected from the wind by an appropriately-placed windbreak. Other groups explored in detail the shadow patterns on a site by creating animated simulations of sunny and shady locations at critical times of the day and of the year. This allowed them to identify opportunities and constraints related to solar access.

5. General discussion

The goal of this study was to identify methods for climate responsive design processes in landscape architectural design education.

In general, from the ‘real world’ cases that the students dealt with, we conclude that the students had a very good learning experience because the stakeholders (mainly municipalities) really used the results of the studio work. Some of the student projects were adopted for further development and partly the work is now even reflected in local climate policies. The fact that some student works were documented by the local media gave the students an even stronger feeling that their work was relevant for society.

More specific for climate responsive design, our proposed process entailed taking three steps:

a) Review and summarize scholarly literature on climate issues related to landscape
b) Analyze the region and site in terms of its effect on climate
c) Develop and test climate responsive design proposals

For the three steps we encountered certain didactic problems and potentials that we would like to share in the following.

Ad a) Review and summarize scholarly literature on climate issues related to landscape

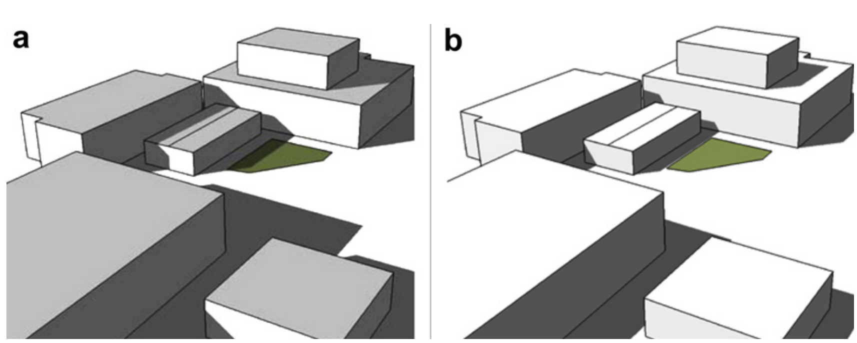

Fig. 11. a, b Plan projection of shadows cast onto the study site at noon on January 1st (left) and October 1st (right) (Andrew Graham).

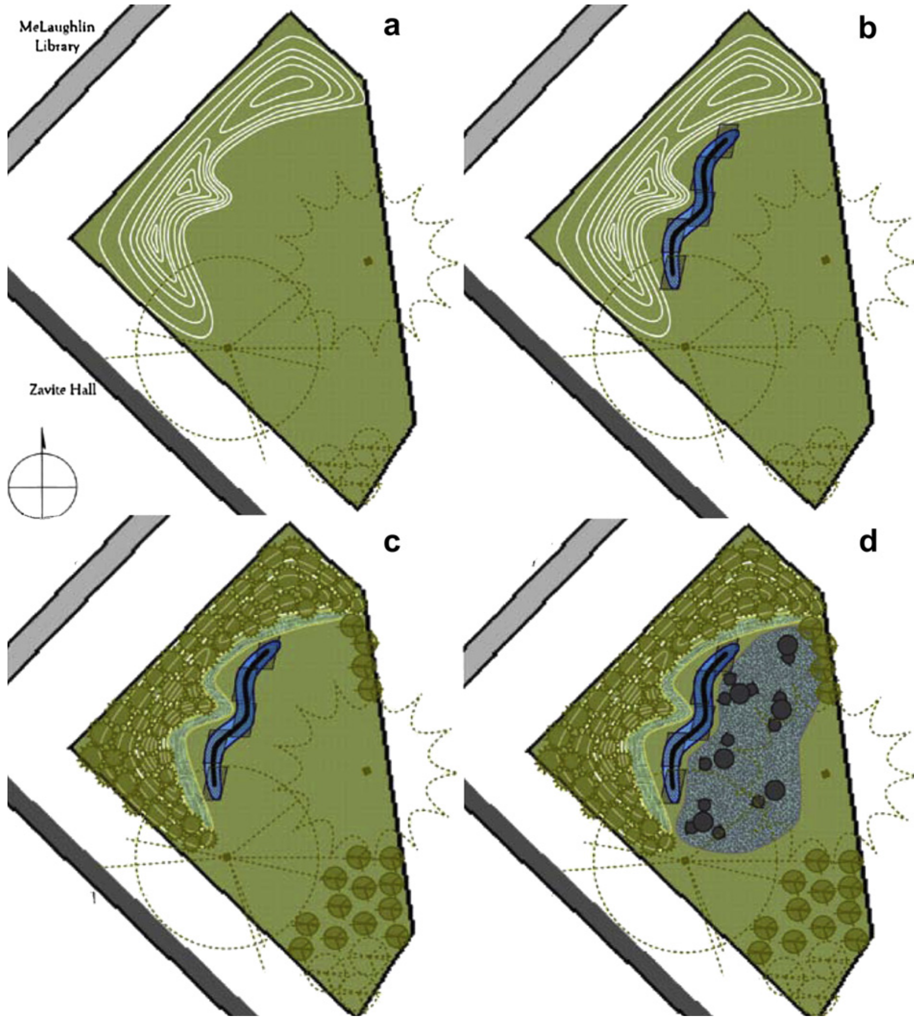

Fig. 12. a–d proposed successive site modifications: placement of berrn (above left), solar-powered water feature (above right), planting (below left), heat-absorbent furniture and a pea gravel surface (below right) (Andrew Graham).

In this phase we faced several challenges when the students had to conduct the literature review by themselves. Firstly, apart from the very basic literature we introduced in Section 1, much of the scientific urban climate information is very scattered. This forced the students to study a wide range of scientific literature which could be very time-consuming. When the tutors noticed that the relation of finding relevant search results and time consumed was out of proportion, the process of literature research was accelerated by providing the students the most important literature.

Another problem was that much of the scientific knowledge – even when it is intended to be used by non-specialists – is incomprehensible (also see Eliasson, 2000). When the scientific knowledge is presented in jargon and complicated formulae it often becomes too big of a challenge for students to make sense of this. On the other hand, it also stimulates the more daring students to 'crack these nuts'. When the students could not tackle this problem, the tutors helped them by explaining the theory.

The third problem was the applicability of scientific knowledge. Often, the problems issued in scientific research are not relevant for spatial design or need some 'translation'. In order to address this problem and stimulate the students to retrieve as much applicable design knowledge from their literature research we asked the students to clearly formulate climate related problems and specify the remedies that they can influence as a designer.

Despite the challenges, we observed some very positive outcomes from this step. Students began to understand energy flows and microclimate modification processes at a deeper level and were able to integrate this with knowledge they had gained in other courses and experiences to generate creative and unexpected insights. Climate information was presented in unusual and sometimes very effective ways by the students.

Ad b) Analyze the city or site in terms of its effect on climate

The results of the analysis phase showed that the students had generally understood the subject matter well and were ready to apply climate knowledge on site. Given the short time frames, most of the students' analyses were rather qualitative and not highly detailed. We do not think that this was a problem, because from our own and other urban climate specialist's experience, it is often not necessary to have highly detailed quantitative data available as a basis for climate responsive design. Such design interventions have to offer climate improvements in many different climate situations, respond to many other local issues such as hydrology, soil, biodiversity, energy and many other issues and are thus somewhat 'generic' and do not require highly specific analysis data.

We noticed that thinking in processes that change over time was very prominent and that these processes had to be analyzed very carefully, for instance changes in seasonal wind directions, the change of shadow paths and temperature patterns. Understanding the dynamics of change and then differentiating the predictable and the unpredictable dynamics are important foundations for climate responsive design in which different climate situations need to be addressed.

Ad c) Develop and test climate responsive design proposals

Consequent considerations of different points in time in climate processes (seasons, extreme situations, etc.) and responding to these situations in the designs made students very aware of the highly dynamic nature of climate and how to strategically and smartly respond to that through design – either by addressing the most important point in time with fixed designs or by flexible designs that change with climate processes.

An interesting side-effect of the focus on climate-responsive design was also that students had to think from one perspective – in this case climate – in a very rigid way. This was quite different from purely integrated design processes that they were used to from previous design studios. This sometimes led to 'out of the box-thinking' and results with very new forms. For example, when students understood that they needed to enhance or reduce energy flows they were willing to explore the effects of a range of unusual or unexpected landscape elements. So, climate-responsive design can be surprisingly inspiring and 'fun'.

When students tested their designs, for instance through the use of the interactive thermal comfort model COMFA they sometimes expressed surprise at the magnitude of the effects. Elements that they expected to have a large effect sometimes had a small effect on the microclimate, and vice versa. This deepened their understanding of the relative effect of design interventions. To give some examples – they were able to understand that in the summertime the most effective strategy is to modify the sun, while in the wintertime the wind has a larger effect on human thermal comfort. They also started to understand that the location of shading devices can be very important, where a tree shading a west-facing wall or an asphalt parking lot can have a much larger effect on urban heat island mitigation than the same tree located elsewhere.

Generally speaking, the testing of designs was another step in the learning curve-designing not only one solution, but several ones helped the students to assess different designs more objectively in an 'evidence based research' and acquire very fundamental knowledge about various design solutions. The constant testing of design proposals brought about a reflective, critical attitude amongst students concerning their own design proposals.

Climate change is literally speaking a 'hot topic' that needs to be addressed much more in urban and landscape design to prepare students for the challenges. It will become necessary that more schools will address this issue in their future curricula and that more tutors acquire sufficient basic climate knowledge to be able to guide such studios. Only if we prepare our 'next generation' sufficiently, we can also guarantee that they contribute to making our cities and landscapes more sustainable.

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