Adaptation Planning Support Toolbox: Measurable performance information based tools for co-creation of resilient, ecosystem-based urban plans with urban designers, decision-makers and stakeholders

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1. Introduction

1.1. Adaptation of urban areas

The need for adaptation of urban areas to changing climatic conditions is widely recognized (Deltaprogramma, 2015; IPCC, 2007, 2012; PROVIA, 2013). Flooding, drought, heat stress and related problems with water quality, water supply and land subsidence, aggravated by the UHI effect, are increasing hazards threatening the liveability of our urban areas as well as our social and economic urban systems (Albers et al., 2015; Jha et al., 2012; Rovers et al., 2014; World Bank, 2010; Zevenbergen et al., 2010). Risks are further increased by on-going urbanization (Nichols et al., 2007; UN DESA, 2014) and by intensification of urban land use; the

invested capital and the asset value of buildings, infrastructure and industrial facilities has increased drastically over the past decades (Kind, 2013). Although the need for adapting our urban environments is clear, in practice adaption is difficult. Opportunities for adaptation are often limited to new development projects, to large infrastructural renovation and renewal projects or to initiatives from individual residents (Van der Brugge and De Graaf, 2010).

Adaptation requires the construction of structural or “hard” adaptation measures (Hallegratte, 2009; Pelling, 2011). Such measures are physical or technological interventions, constructed facilities that require space and therefore are subject of spatial planning and design (Taylor and Wong, 2002). This article will focus on the right design of structural adaptation measures, as embedded in a planning process that leads to a decision on a spatial adaptation plan.

The pallet of adaptation measures has extended dramatically over the past decades. Earlier, Sustainable Urban Drainage Systems (SUDS) (CIRIA, 1998; Svenske Vatten- och Aflopsverksföreningen,
1983) and Water Sensitive Urban Design (WSUD) for urban drainage (Brown et al., 2008; Engineers Australia, 2006), nowadays also known as green or blue-green infrastructure, were introduced. Maksimovic et al. (2014) recently argue that a new concept of Multiple-Use Water Services (MUS) is emerging. MUS solutions enhance the synergy of urban water (blue) infrastructure with green assets and ecosystem services, are economically viable and climate (environmental) adaptive.

Ecosystem-based Adaptation (EbA) is at the heart of this MUS development. EbA measures integrate the use of biodiversity and ecosystem services into an overall strategy for helping people adapt to climate change (Munroe et al., 2012). In addition to flood control, drought mitigation and heat stress reduction they provide e.g. aesthetic quality, recreational and restorative capacity and health benefits (Opdam et al., 2009; Van den Berg et al., 2007; Van den Berg et al., 2015). This article shows how planning ‘blue-green’ EbA measures is used to advance climate resiliency, while maximizing their co-benefits.

1.2. Adaptation planning

Urban planning exists of a series of more or less consecutive phases starting from system analysis and program development (initiative phase), via conceptual, preliminary and final design (design phase) up to implementation (Fig. 1). The process ends with a final decision on an adaptation or (re)development plan. Although shown as a straightforward, stepwise process in theory, the process in practice often reiterates to an earlier stage to investigate alternative adaptation pathways.

Many guidelines on climate resilient urban planning provide procedures for hazard, exposure and vulnerability analysis and an overview of potential solutions and/or best practices (Challenge for Sustainability: Climate-ADAPT; Deltaprogramma N&H, 2014; EPA; Great Lakes and St. Lawrence Cities Initiative; PROVIA, 2013). They however lack guidance where it comes to the selection of appropriate packages of adaptation measures during the initiative and design phases (Voskamp and Van de Ven, 2015). For these phases tools seems unavailable to support stakeholders to make hard choices which adaptation measures are attractive and effective for the project area (Bours et al., 2014; PROVIA, 2013); this while complex simulation models to evaluate the expected hydraulic and hydrological performance of the final plan are readily available (Lerer et al., 2015)

In the initiative phase, urban planners are often in the lead of the process. Eliasson (2000) showed that climatology so far has a low impact on the planning process; urban planners’ use of climatic information is unsystematic as the urban climatologists fail to provide them with good arguments, suitable methods and tools. This underlines the need for a planning support system that bridges the gap between urban planners and engineers; she makes a plea for a “communicative approach” to the planning process.

1.3. Adaptation support tools for collaborative planning

Involvement of local stakeholders, land & water engineers, experts from other disciplines and decision-makers is considered essential in particular in planning reconstruction of existing urban areas. Each of them not only has different interests, agendas and roles in the process. They differ in their sense of urgency of the problem, their approach to the problem, their language and knowledge level, and their rationality regarding potential solutions (Van Stigt et al., 2015). Design workshops during the initiative phase are meant to get to know each other, to share each other’s knowledge and understanding of the problems and to collectively identify interesting adaptation solutions.

Question is how to support the planners, stakeholders and decision-makers in this analysis – dialogue – design-engineering process with knowledge and information, in order to get a converging learning process that leads to a final positive decision on an adaptation plan? Such planning support tools should raise awareness, present the broad range of adaptation options, let participants explore the impact of different design choices on the climate resiliency of their project area (Pelzer et al., 2013) and maximize the co-benefits of adaptation measures.

Goal of our study was to develop a toolbox that supports the incorporation of climate adaptation in the actual planning and design practice in cities. This Adaptation Planning Support Toolbox was developed to provide urban planners, landscape architects, civil engineers and local stakeholders and decision makers with quantified, evidence-based information on the climate resilience of their ideas in early phases of the planning process and to facilitate decision-making during conceptual design workshops. In design workshops the toolbox should supports them in how to share their knowledge and discuss alternative measures, including location, size, costs and (co)benefits.

Fig. 1. Adaptation planning process, stakeholder engagement and planning support tools. Both tools (bold) in the Adaptation Planning Support Toolbox will be discussed in this article.
2. Toolbox to support adaptation planning

2.1. An integrated ‘dialogue – design – engineering’ planning process

The Adaptation Planning Support Toolbox was developed to effectively support the collaborative planning process in the phases of program development and/or conceptual planning. See Supplementary Material part A for underlying principles and concepts. Two actual tools were developed to support the ‘dialogue – design – engineering’ planning process (Fig. 1). The Climate Adaptation App (climateApp) informs participants about more than 120 potential adaptation measures and produces a long list of relevant measures. The Adaptation Support Tool (AST) guides stakeholders in the next step, the conceptual design. Resulting conceptual plans are input for urban planners and designers, to make detailed preliminary designs.

The climateApp and the AST are both web-based software tools running on touch enabled hardware. This because a touch table facilitates ‘reasoning together’, is community supportive, empirically based, experimentally oriented and information and knowledge disseminating (Geertman, 2006).

2.2. Climate adaptation app

The Climate Adaptation App was developed to start the design workshop with overview and pre-ranking of potential measures for all participants (www.climateapp.org or Appstore/Playstore). From different publications (Pötz and Bleuzé, 2012; Van de Ven et al., 2009; Vergroesen et al., 2013) a list of over 120 structural adaptation measures was composed. The app provides information on each measure and ranks measures for potential applicability based on local circumstances and preferences by toggling the different filters (Fig. 2).

Design workshop participants go through the list and discuss applicability and attractiveness of potential measures to create a long list for their project area.

2.3. Adaptation support tool

The Adaptation Support Tool (AST) is a touch-table based platform that design workshop participants may use to select adaptation interventions, situate them in their project area and immediately see an estimate of their effectiveness and costs (Fig. 3). The AST consists of a left panel for input, a middle panel for design (map of project area) and a right panel as an “AST dashboard” for output.

The current AST version includes a long list 62 blue, green and grey adaptation measures for reduction of pluvial flooding, drought and heat stress (see supplementary material C), a selection assistant for ranking their applicability and an assessment tool to estimate the effectiveness of applied measures. The left panel shows a ranked list of adaptation interventions. The long list of measures has been composed from multiple inventories found in literature. The selection of measures was based on criteria that differ for blue-green and for grey adaptation interventions. As many blue-green interventions were included that the authors and project partners are aware of from both literature and practice. We however selected traditional/grey solutions in such a way that a comparison between traditional and blue green solutions can be made when planning alternative solutions and because traditional

![Figure 2](image-url)
interventions can enhance the effectiveness of blue-green interventions. Based on local common practice additional interventions can be added. Ranking of the measures is determined on characteristics of the area and adaptation targets (Voskamp and Van de Ven, 2015). These targets differentiate between threshold capacity for damage prevention and coping capacity for damage minimization in case of a failing protection system (De Graaf et al., 2007).

In the central panel different map layers can be shown. Default a Google Earth and OpenStreetMap layer are provided, with layers like surface elevation, land ownership, flood depth, heat stress maps or future land use as additional. Design workshop participants can now select a measure from the list left and draw it in the project area on a map layer, on the location where they think that it would provide added value. For example, the user can apply a green roof on a large flat roof, install permeable pavement on sidewalks and artificial wetlands near the outlet of a tributary drain. Next, the tool requests the water storage depth of the measure and the additional contributing inflow area.

On the basis of this input, the AST estimates a number of performance indicators, e.g. storage capacity, normative runoff, heat stress reduction, water quality effects, costs and additional benefits. These performance estimates are shown on the right panel. Under the Details tab (not shown) the contribution of each proposed measure to the adaptation targets is given in combination with the estimated costs for realization and maintenance. Users can also switch to the Overview tab of the right panel, as shown in Fig. 3, to get a summary of the measures and their total effectiveness in relation to the adaptation assignment.

Results of a session can be saved as snapshots and re-opened at a later moment. This way alternative plans can be created and compared. The tool is web-based and can run both on a webserver and standalone.

2.4. Adaptation performance indicators

The current selection of performance indicators was based on the demand of participants of the design workshops and the role of water as the key to a climate resilient urban environment. The indicators are listed and explained extensively in the Supplementary Material part B, including underlying scientific evidence. The quantified performance indicators include estimated changes of physical characteristics that are relevant for damage reduction, resilience, public health and feasibility.

- Prevention of flooding due to extreme rainfall requires effective storage (retention) of water as well as peak flow reduction. Created storage volume is shown, as this has to comply with the target volume that our water managers set to reduce pluvial flood risk. The normative runoff frequency allows for estimation of flood risk reduction in terms of a reduction in frequency of a certain peak flow. Estimates of these flood prevention indicators are based on the result of simulation of the effect of a specific adaptation measure, using long time series of rainfall and
evaporation – 30 years or more –, a climate change scenario, a multi-reservoir rainfall-runoff water balance simulation model, a theoretical design of the intervention and extreme value analysis to quantify changes in effective storage capacity and peak flow reduction. Parameters characterising the hydrological performance of the specific adaptation measures were taken from experimental results reported in the international scientific literature.

- Drought control requires groundwater recharge information and inter-seasonal storage of water, in particular in areas prone to land subsidence or a lack of replenishment due to soil sealing. On the other hand, in case of very shallow groundwater tables high recharge rates would lead to the need for subsurface drains. Estimated groundwater recharge also results from output of the multi-reservoir simulation model and a theoretical design of the intervention. Average annual recharge change is calculated as a performance indicator.

- Heat stress reduction is achieved by provision of shade and evaporative cooling from vegetation and water surfaces; though, to that end vegetation has to have enough water available, which is related to groundwater recharge. Heat stress reduction is based on the reported observed cooling effect of blue-green infrastructure in Dutch urban areas and scaling based on the dimensions of the measure.

- The quality of the water is essential for the functions and services it can provide. To evaluate potential functionality water quality improvement of the blue, green and grey adaptation measures is expressed by three indicators: nutrient reduction, absorbed pollutants reduction and pathogen reduction. These water quality performance indicators are determined as a pollution reduction factors based on recorded effectiveness of treatment processes in a facility and scaling based on the dimensions of the measure. Nature based treatment processes included in the pollution reduction factor include natural degradation, settling and soil filtration. For intensive green roofs fertilization was included as a negative pollution reduction factor for nutrients.

- Average costs of construction and costs of management and maintenance are estimated for each adaptation measure based on unit prices on the Netherland’s market.

The purpose of the AST is to provide estimates on the effectiveness and costs of adaptation interventions in the early planning phase of urban (re)development projects, in order to meet adaptation targets. Such targets can be met by different packages of measures. No framework or guidelines are provided for the selection specific adaptation measures; the AST allows for any strategy to reduce its vulnerability (De Graaf et al., 2007). The actual effectiveness and costs will depend on the implementation which is determined by exact local physical conditions, and specific wishes and ambitions of the stakeholders.

3. AST applications

In the period 2014–2015 the Adaptation Planning Support Toolbox has been used in adaptation processes in different cities (Table 1). Being both AST developers and participant, we learned valuable lessons concerning the optimal use of the Toolbox for local adaptation process. Two examples are briefly addressed here.

3.1. Beira, Mozambique

The city of Beira (Mozambique) frequently floods by heavy rain, having serious health and economic impacts for the 0.5 million residents. Blue-green adaptation measures may increase water retention capacity and will improve the liveability. Discussing adaptation strategies with local Beira stakeholders in a workshop setting has been done based on the following steps (Picketts et al., 2012):

3.1.1. Building capacity

Municipal civil servants, representatives of the Chota neighbourhood (pilot area), and local university staff (UCM) were briefed by the authors (acting as facilitators) on climate adaptation and the key role the workshop participants have in adaptation planning as experts with important local knowledge.

3.1.2. Identifying local impacts and vulnerabilities

Climate information was distributed before and during the workshop. It included information on hydrology in urbanized delta regions, flooding maps of Beira based on 3D aerial information, historical climate information and future predictions. The maps and explanation provided a good overview of the impacts and vulnerabilities of Chota and surroundings, including underlying mechanisms. For most workshop participants especially the hydrodynamic information was new, enabling them to better

Table 1
Overview of applications of the Adaptation Planning Support Toolbox.

<table>
<thead>
<tr>
<th>Area</th>
<th>Project area type and size</th>
<th>Type of project/ spatial planning process</th>
<th>Climate challenges</th>
<th>Phase of planning process</th>
<th>Participants</th>
<th>Experiences, Lessons learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chota - Beira (Mozambique)</td>
<td>788 ha, district + detail</td>
<td>Redevelopment &amp; development</td>
<td>Flooding</td>
<td>Program formulation</td>
<td>Municipality, citizens, politicians, local university, NGOs</td>
<td>Stakeholder sessions including non-professionals demand a combination of high tech (AST) and low tech process tools</td>
</tr>
<tr>
<td>Decoy Brook, London (United Kingdom)</td>
<td>292 ha district + detail</td>
<td>Research</td>
<td>Flooding</td>
<td>Conceptual design</td>
<td>Environment Agency, Borough reps., university</td>
<td>Make plans for both full area and detailed design for focal hot spots</td>
</tr>
<tr>
<td>Oaxaca (Mexico)</td>
<td>195 ha development</td>
<td>Redevelopment</td>
<td>Flooding, drought</td>
<td>Program formulation</td>
<td>State and municipal authorities, citizens, university, NGOs</td>
<td>AST is a very handy tool as a catalogue of possibilities in district zones within different characteristics</td>
</tr>
<tr>
<td>Utrecht (Netherlands)</td>
<td>49 ha</td>
<td>Redevelopment</td>
<td>Flooding, heat stress</td>
<td>Conceptual design</td>
<td>Municipality, real estate owners, architect; urban water and green experts; Students</td>
<td>Participants go for urban quality rather than for cost reduction</td>
</tr>
<tr>
<td>Dordrecht (Netherlands)</td>
<td>65 ha</td>
<td>Student Climate Resilient Urban Design workshop</td>
<td>Flooding, heat stress</td>
<td>Conceptual design</td>
<td>Municipality; urban water experts</td>
<td>AST toolbox is effective training tool</td>
</tr>
<tr>
<td>Tilburg (Netherlands)</td>
<td>46 ha, neighbourhood</td>
<td>Research</td>
<td>Flooding, heat stress</td>
<td>Program formulation</td>
<td></td>
<td>The AST can also be applied as a quick-scan method to assess e.g., green roofs have an added value for specific urban areas</td>
</tr>
</tbody>
</table>
identify the causes of flooding and the ways flooding can be prevented.

3.1.3. Determining priorities and outlining implementation

The workshop participants defined short and long term targets to prevent frequent and large-scale flooding of their residential areas in the future. The facilitators calculated the overall retention capacity to achieve these goals. The facilitators then explained about the AST: the goal, the lay out of the AST tools, the range of measures and underlying data. Based on local knowledge the participants selected a number of measures that fit local physical conditions and culture: surface water bodies (channels, small lakes, lagoon), multifunctional green (public green fields that can be inundated temporary). Measures demanding high-level construction and maintenance (e.g. green roofs, technical installations) were rejected, not fitting the local possibilities in water management. Locations within the Chota area where measures could be implemented were identified (Fig. 3). For each location and accompanying measures the AST calculated water retention capacity and other parameters, based on local meteorological data. By doing so, it became clear for the participants that additional retention nearby Chota was needed, resulting in a proposal for a lagoon development adjacent to Chota. Through field visits the workshop participants together with the municipal board verified whether implementation of the measures (including lagoon) was indeed possible. Most of the recommended interventions were accepted by the municipal council; in one occasion however a land development claim became the topic of discussion, because this development would decrease retention opportunities for the larger area. The mayor of Beira expressed his intention to reject that claim. The total set of measures was further elaborated on a map and – together with the other information – presented in a report (Kalsbeek, 2015). See this report for more details and background information on this case. The Chota adaptation plan as composed by the workshop participants and their facilitators was also welcomed at an international financing meeting in September 2015; it now serves as the outline for detailed design of drainage improvement works.

3.2. Utrecht, the Netherlands

In the redevelopment of the Utrecht City Centre – West, there is a need for a more climate resilient, attractive and pleasant accommodation area. Using the AST, stakeholders sketched three alternative plans, selecting different adaptation measures they deemed applicable and effective. Two of these alternatives can be seen in Fig. 4. To make the area more attractive and to reduce the heat stress emphasis was put on greening the area, both at street level and by creating green roofs and urban agriculture on the roofs of the large exhibition halls in the area. Stormwater retention

![Image](image.jpg)

**Fig. 4.** Example of AST application: Two of the alternative conceptual adaptation plans for the Utrecht City Centre—West, each with its own set of adaptation measures and, consequently, a different contribution to adaptation targets and co-benefits. The Green alternative (right) proved less effective than the Plus alternative (left) (Van de Ven et al., 2016a,b). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
capacity was also created by installing rain tanks, a water square and application of porous pavements. The design workshop participants managed to meet the climate adaptation targets they had set in advance, while creating substantial co-benefits for themselves, for future residents and for the numerous visitors of this area (Van de Ven et al., 2016a,b).

3.2.1. Building capacity

Representatives of different municipal offices (including urban planning, health, water management, urban green and project development) and representatives of the private stakeholders participated in the Climate KIC Smart Sustainable District project on the sustainable and climate resilient redevelopment of the Utrecht Centre West area and two design workshops. These parties learned about the vulnerability of the area for flooding, drought and heat stress and about the many potential solutions that can be used to strengthen resilience, meanwhile delivering substantial ecosystem, economic and social services.

3.2.2. Identifying local impacts and vulnerabilities

National climate change scenarios are available for the Netherlands (KNMI, 2015). Flood hazard maps and heat stress maps showed significant climate risks in the project area. Drought however turned out to be less of an issue. An attempt to map all critical and vulnerable objects, networks and population groups for a risk assessment turned out to be complicated. Information is scattered over very many desks. Impacts and vulnerable spots were recognized by the participants of the design workshop.

Adaptation targets for stormwater retention, peak flow reduction and heat stress reduction were quantified on the basis of these climate and land use projections. These targets, though negotiable, are used to evaluate performance of the packages of adaptation measures.

3.2.3. Determining priorities and outlining implementation

The workshop participants first used the ClimateApp to get an overview of potentially applicable solutions; most of them were not familiar with the large variety of potential adaptation measures they discovered and learned about other solutions. After that first step they started discussing the applicability and attractiveness of implementing specific adaptation measures on specific sites in the project area. Two alternative plans emerged from this discussion: a blue-green alternative and a high density urban alternative. Both alternatives did not completely meet adaptation targets. That is why a third alternative was produced, the Plus alternative. This alternative combines measures from both the Green and the Urban alternative and meets the adaptation targets on storage/detention capacity and peak flow reduction. Heat stress reduction targets are met at all places where people stay, walk or bike. A first analysis was made of the ecosystem services, the economic and social benefits of the proposed alternative adaptation plans as well as a qualitative analysis of who benefits from implementing the Plus alternative and in which way.

The blue-green adaptation plans are now being merged with the mobility adaptation plan and the energy transition plan for the project area to produce comprehensive redevelopment plan alternatives. These alternatives will be used in 2016 (a) to evaluate if adaptation targets are still being met, (b) as input for public engagement sessions and (c) as basis for a value case analysis. This value case analysis is meant to specify the benefits and the beneficiaries of the redevelopment plan in more detail and use this as a basis for a fair distribution of investment and maintenance costs. Results of this value case analysis are meant to support final decision making in 2017 by the City of Utrecht and private stakeholders and project developers on the urban and economic development of the Utrecht City Centre-West area.

4. Discussion

4.1. Addressing adaptation in city planning and design

Local adaptation of our urban infrastructure, buildings and environment is required to minimize negative consequences of climate change. A wide variety of blue, green and grey infrastructural measures is available to strengthen resilience against flooding, drought and heat stress. Decisions are to be taken about adaptation targets and about where and how which adaptation measures are to be located. Such an adaptation plan is to be produced in a collaborative planning process of urban planners, engineers other experts, local stakeholders and political decision makers.

Overall, more and more cities recognize the need for adaptation at a policy-level, but lack the practical instruments to go from vulnerability assessments towards adaptation-inclusive urban planning – see e.g. [ND-GAIN, 2016] – and lack of support for adaptation investments. Moreover, adaptation is a relative new phenomenon, not considered by everyone as his/her responsibility (Nalau et al., 2015). Investors seem to focus on cost reduction rather than on long term benefits of implementing adaptation measures. The fact that most ecosystem-based adaptation measures not only reduce vulnerability of the urban environment to extreme weather events but also produce substantial economic, ecological and social benefits for the citizens is often overlooked, let alone maximized in spatial planning, partly due to the fact that these benefits are hard to quantify. This lack of quantitative information is partly overcome by implicit evaluations that take place while the participants in this collaborative planning process evaluate the performance information produced by the AST.

4.2. Role of tools in planning for climate resilience

Urban planning and design routine is not equipped yet to easily incorporate climate proofing. To gain public support, there is a need for stakeholder participation when addressing adaptation in city practice (Hurlbert and Gupta, 2015). In a collaborative planning workshop based setting local stakeholders are able to provide their implicit knowledge of the area and of the community's preferences (Picketts et al., 2012; Van Stigt et al., 2015). Many stakeholders however are not aware of the large variety of adaptation options to choose from – the AST contains 62 –, each with their own pro’s and con’s. Planning and decision support tools for climate resilient urban design should therefor support knowledge sharing and collaborative exploration of alternative adaptation solutions in community-based meetings. To effectively support policy making, planning support tools should bridge the gap between the worlds of scientific expertise and self-organised adaptation in urban reality (Larsen et al., 2012; Löschner et al., 2016) and that of the creative urban planner.

Pyke et al. (2007) conclude that the existing decision support systems are more effective when they balance the provision of information with concern for organizational and political process-es.

4.3. Application experiences with the Adaptation Planning Support Toolbox

The Adaptation Planning Support Toolbox has effectively supported climate-proof planning in several cases on different continents. Participants of the design workshops expressed their satisfaction with the way the planning process was structured, with the ranked overview of potential blue, green and grey adaptation measures and with the estimates of the effectiveness and the costs of proposed measures; this information supported a
learning process and informed decision making. Concerns on organizational or political issues around details of the plan were discussed among participants at the design table. As such there seemed no need to include such issues explicitly in the tool.

The toolbox builds on the results of vulnerability assessments and on the willingness to adapt, as e.g. analysed with the Uniform Adaptation Assessment (Chenchen, 2015) or the Climate Stress Test (Deltaprogramma N&H, 2014). Flood hazard maps, heat stress maps and water balance calculations provide valuable information on where to concentrate adaptation efforts. In practice it turned out to be hard to formulate adaptation targets for drought and heat stress. The AST was in such cases used to explore the feasibility of a certain impact reduction.

The use of the AST in design workshops requires skilled facilitation. The dialogue that takes place around the design table benefits from an independent facilitator. Moreover, the use of the AST proved to be complex for participants that are not familiar with design workshops and/or with the wide range of potential adaptation measures. In practice, the facilitator or another professional that is trained in the use of the tool assists the application. The Climate Adaptation App is available as a stand-alone tool, because this tool can be used for individual learning by professionals and non-professionals around the globe.

And although decisions on the application of adaptation measures suffer from deep uncertainties on expected climate change and exposure, we have seen in practice that many adaptation measures are selected because of the expected co-benefits of the blue, green and grey measures for the liveability and economic functioning of the urban environment; climate resilience was dealt with as a valuable co-benefit rather than a primary target – as long as adaptation targets were met.

As concluded by Pelzer et al. (2013), the use of a touch table during the design workshops proved to be effective in supporting the planning process. The use of the touch table supports learning processes and stimulates thinking beyond the own professional roles. Moreover, the performance indicators shown on the touch table forced participants to be explicit about their proposed interventions and the expected effectiveness. The struggle they reported of the urban planners with the application of the touch table is interesting. Designer’s working practice, to which intuitive sketching and visualization are central, is disrupted by the use of the touch table. This was solved by having regular maps, transparent and drawing pens next to the touch table, so that they could sketch their ideas when they felt the need for it. According to Pelzer et al. (2013) designers also felt the integral approach as a barrier to their creativity. This could not be confirmed in our workshop, potentially because the objective of our workshop was more specific than the objective of their workshop – create a more climate resilient and attractive urban area versus planning a more sustainable new urban area.

4.4. Usability and reliability

Performance indicators produced by the AST and used to select and plan adaptation measures are based on evidence-based key figures on the characteristics, performance and costs of each adaptation measure retrieved from international literature (De Jong et al., 2014, 2015; Geisler and Barjenbruch, 2015; Kosteninformatie.nl, 2015; Vergroesens et al., 2013). They are also based on conceptual modelling of the measure’s performance using local climate and land use conditions. Although the accuracy is limited we argue that this information is reliable enough to compare different measures and different alternatives and to find a common preference with all participants. Arguments to decide on a specific choice are exchanged, while keeping an eye on their contribution to the adaptation targets and on their cost-effectiveness.

Conceptual designs are so far made without quantified information on performance of proposed adaptation measures; the availability of a more or less reliable performance and cost estimation is a valuable contribution to informed decisions on the selection and design of adaptation measures.

The Toolbox is used for planning problems at building to district scale; use at larger scale level is questionable because the tools do not consider interconnections and flow capacities between adaptation measures. Estimated performance at larger scale could consequently be misleading.

Moreover, the AST shows only performance indicators regarding climate resilience in relation to the water system and estimated costs; other benefits and co-benefits of the measures – e.g. landscape quality, added economic and social value – are not quantified, but in practice play an important role in the dialogue and selection decisions of the workshop participants. Quantified information would give the benefits a more equal treatment in the selection and decision making process as compared to the costs. Research to find out which information on co-benefits session participants would like to see on the AST dashboard is on-going.

Measures against heat stress tend to have local effects. In order to evaluate heat stress control measures we would like to visualise the local cooling effects of planned blue green measures in a map instead of presenting a general decrease in average area temperature as a figure on the dashboard. We planned to realise this functionality in 2016.

Another relevant question is who should participate in the design workshops. Participation of urban planners, landscape architects, water managers, civil engineers, local stakeholders and other experts is evident. But how about participation of city council members and commercial developers? The fact that city council members participated in the design workshop in Beira turned out very effective for further decision making. In other cases political decision makers were not invited by the host of the design workshop; further study is required to evaluate the impact of their participation.

The toolbox was used both in the Netherlands and abroad. For the applications in Beira and London the key figures for calculating the performance indicators of each measure had to be calculated with the local climate and local land use data. So far this has been done manually and has required substantial effort. For easier applications abroad this process could be automated. Cost figures remained unchanged so far; if local unit cost figures are available these can be brought in the tool without much effort. Moreover a stronger coupling (export-import function) of the AST with hydraulic and hydrological simulation models for plan evaluation would be convenient.

5. Conclusions

There is a gap in the tools available to support resilient, climate-proof urban planning. Tools and procedures are available for climate vulnerability assessment and for evaluating the performance of final designs with the help of simulation models. But tools that have the ability to support implementing adaptation in the actual urban planning and design practice, i.e. to support defining the program of demands, setting adaptation targets, for selecting adaptation measures from a wide variety of blue, green and grey adaptation measures and for informed co-creation of a conceptual design, seem to be missing.

To close this gap and support the planning of a climate resilient urban environment we developed and tested an Adaptation Planning Support Toolbox. The toolbox contains a Climate Adaptation App (climateApp) and the Adaptation Support Tool (AST). From our applications so far we conclude that this Toolbox meets the demands of local policymakers, planners, designers and
practitioners to provide evidence-based support for their collaborative analysis – dialogue- design-engineering (=planning) sessions. Participants appreciated the AST because its overview and pre-ranking of a wide range of potential adaptation measures, the possibility to create different adaptation design options (scenarios) for their own project area, and to explore the contribution of these options on adaptation targets and co-benefits. Discussions on the design table were focussed on the opportunities and the benefits of specific interventions, rather than on the costs. The combining of informing, exploring and testing at the same time, and doing this in a collaborative dialogue with relevant stakeholders, is considered as of added value to current adaptation planning practice.

Essential is that urban planners, landscape designers, water managers, urban green managers have to learn how to combine their working practice in such a collaborative planning and design process. This transition requires courage and perseverance from all parties, and will lead to further development of the toolbox or similar tools. With more and more cities worldwide that will make the step from climate policymaking to an actual adaptation-inclusive urban (re)development practice we foresee a growing demand of tools like the climateApp and the AST to ensure that adaptation will be seriously adopted by the local actors while maximizing the social and economic co-benefits of the adaptation measures.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1610/j.envsci.2016.06.010.

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