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Adapting urban areas in developing countries: Additional criteria for the Adaptation Support Tool

Additional criteria for the selection of adaptation measures in the urban environment based on different circumstances in developing countries and different climatic conditions

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Abstract

Human activities have caused the atmosphere of the Earth to change rapidly leading to an increase in extreme weather conditions and climate related hazards. As the effects of climate change are more severe in developing countries than in developed countries, urban areas in developing countries are extremely sensitive to these climate hazards. To make this environment less vulnerable to the impacts of climate change, it is necessary that urban areas can adapt to these changing conditions. This adaptation can be achieved by the implementation of grey, blue and green measures. However, as urban areas are densely built and many stakeholders are present, the implementation of these adaptation measures is a difficult process. Hence, climate adaptation should be included in the urban planning, although this complicates the decision-making process. As stakeholders require support in the evaluation of the numerous adaptation measures, Deltares developed the Adaptation Support Tool to assist in the complex urban planning process. The main goal of this tool is to offer support during the conceptual planning processes of stakeholders in their efforts to make the urban area more resilient to climate change, by offering information on adaptation measures and their effectiveness. However, the selection criteria to select adaptation measures are currently less applicable in developing countries due to different climatic conditions and different circumstances in these countries. Thus, additional selection criteria have been included to improve the performance of the tool.

An extensive literature review has shown that the circumstances in developing countries are very different from the circumstances in a more developed environment, and that climatic conditions have a large spatial variability over the globe. The findings of this review have resulted in a set of six additional selection criteria specifically aimed at the feasibility of the adaptation measures under the different circumstances and climatic conditions. These selection criteria include the preferred construction costs and the preferred maintenance of the adaptation measures, the existing infrastructure and the presence of solid waste in the urban environment, the preferred technological complexity of the adaptation measures, and the different climatic conditions on the earth. Both a feasibility ranking and ranking indicators were determined to reflect on the effectiveness of the adaptation measures based on these additional selection criteria. The measures in the tool were ranked according to these indicators and feasibility, which was implemented in the Adaptation Support Tool. Additionally, the visual presentation of the tool has been adjusted to incorporate the additional selection criteria. Two broad case studies have shown that the inclusion of the additional selection criteria could generate a list of adaptation measures more feasible in developing countries with different local circumstances and climatic conditions. Consequently, the support offered by the Adaptation Support Tool during the conceptual urban planning process to make urban areas more climate resilient has been improved with the inclusion of the additional selection criteria. However, additional expert-judgement of the feasibility ranking and an extensive on-site evaluation could improve the performance of the tool as this would allow for a more precise study of the effectiveness of the additional selection criteria.

Contents

1. Introduction

1.1.1. Climate change

The climate has been changing worldwide and is expected to continue to change in the future. [1] Human activities have caused the atmosphere of the Earth to change rapidly, especially due to the burning of fossil fuels. This activity has caused the amount of clouds, aerosols and greenhouse gases in the atmosphere to increase with a rate that greatly exceeds the impact of volcanic eruptions and other natural processes. [2] Global surface temperatures are likely to increase significantly worldwide and as a result the mean sea level is subject to a substantial increase as well. Besides increasing average climate conditions, a substantial warming in temperature extremes is projected for the near future. The magnitude and frequency of warm temperature extremes will increase while at the same time cold temperature extremes will decrease. In addition, it is very likely that the frequency, intensity and duration of heat waves and warm spells will increase over most land areas. The Intergovernmental Panel on Climate Change (IPCC) further projects that heavy precipitation events will occur more frequently and with greater intensities and amounts. At the same time, droughts will increase in intensity and occur with both greater duration and frequency in the future. [1, 3]

1.1.2. Climate hazards in the urban environment

Apart from climate change, continuing population growth and urbanization are expected to increase the total world's urban population to 2.5 billion people. Currently, the urban population already exceeds the rural population, with 54% of the world's population living in urban areas. Because of further profound changes in the size and spatial distribution of the global distribution, the United Nations project that this number will increase to 66% by 2050. [4] Moreover, the total urban area of developing countries will have increased threefold to 600,000 km^2 by 2030, compared to an area of 200,000 km^2 in 2000, while its population will have doubled. [5] Additionally, urban areas magnify the effects of climate change due to the high concentration of socio-economic activities and the highly concentrated presence of buildings. [2, 6] Hence, urban areas are especially sensitive to several hazards as a result of extreme weather conditions. These hazards include pluvial, fluvial and coastal flooding, heat stress, droughts and problems related to water quality, water supply and land subsidence. [7, 8]

Pluvial flooding is flooding as the result of high intensity precipitation events. As the surface areas in the urban environment are often subject to low permeability, the infiltration capacity of these areas is decreased. High intensity precipitation events could therefore lead to more stress on the existing open surface water bodies and drainage networks. [9] Similarly, in river basins extreme precipitation events characterized by high intensities and large amounts could lead to fluvial flooding. These precipitation events could generate high water levels in rivers, which in turn could cause these rivers to burst their banks and potentially flood urban areas. [10] Contrary, coastal flooding is caused by rising sea levels as a result of rising average temperatures. [1] Combined with the effect of land subsidence, the risk of coastal flooding is increased significantly for urban areas in coastal areas. [11]

Besides the risk of flooding, the urban environment is also subject to the effect of heat stress. According to the IPCC, heat stress causes a loss in productivity of the population in urban areas and has a large range of adverse health effects. [9] These adverse effects are further emphasized by the urban heat island effect, as this effect can cause temperatures in urban environments to be 10 ºC higher than in nearby rural areas. [12] The temperature raise is mainly caused by large surfaces of non-reflective materials and the absence of vegetation in urban areas, reducing the cooling effect otherwise caused by shading and transpiration. Additionally, the production of excess heat and the obstruction of rural air flows by built-up surfaces further magnify the urban heat island effect and the risk of heat stress in the urban environment. [13]

Along with the exposure of urban areas to increasingly heavier precipitation events, these environments will also experience periods of less or no precipitation, leading to more and more extensive periods of droughts. [3] Due to the presence of low-permeable surfaces in urban areas the infiltration capacity of the soil is decreased. Thus, the water quality of surface water bodies will reduce, groundwater levels will reduce, which could potentially lead to land subsidence, and vegetation will have less access to water and lose their cooling effect. [11]

1.1.3. Climate adaptation

To make the urban environment less vulnerable to the aforementioned impacts of climate change and its associated hazards, it is necessary that urban areas can adapt to these changing conditions. This emphasizes the importance of climate adaptation: “the process of adjustment to actual or expected climate and its effect, to moderate harm or exploit beneficial opportunities”. [3]

Urban areas can be adapted using various measures, ranging from enlarging the sewer capacity to constructing green roofs. Traditionally grey measures -e.g. sewage systems, concrete structures, pumping stations- are used to facilitate climate adaptation, mostly relying on technology and civil engineering projects. [14] Although these measures only use artificial solutions focused on the direct impacts of climate change on infrastructure and buildings [15], they are still effective measures. Blue-green measures however, have the potential to incorporate natural and semi-natural processes and spaces, utilize underlying ecosystem function and generate other social, cultural and economic co-benefits. Additionally, blue-green measures could be more cost effective, more flexible and contribute to a more sustainable environment. [11, 16]

Although numerous measures exist, the adaptation of the urban environment by implementing these measures is a difficult process. Existing urban areas in both developed and developing countries are densely built and a large number of stakeholders is involved. Thus, climate adaptation is complicated by multiple technical and social issues.

1.1.4. Adaptation Support Tool

To assist in the complex urban planning process and facilitate the implementation of grey, blue and green adaptation measures in the urban environment, stakeholders, designers and planners require support in the evaluation of the numerous adaptation measures. [16] To determine the most appropriate solution for a project location, Deltares has developed the Adaptation Support Tool (AST) to “support during the conceptual planning processes of stakeholders in their efforts to make the urban area more resilient to climate change”. [8] This tool allows users to define their program of demands, their adaptation targets -drought, heat stress or flood adaptation- and several environmental characteristics. The AST provides more than 65 grey, blue and green adaptation measures to select and implement in conceptual urban adaptation plans. The AST provides information on the effectiveness of these measures regarding climate, water quality, additional potential interests and costs. [8, 11]

1.2. Problem definition

The Adaptation Support Tool has been used in numerous cases and has shown its added value in the urban planning process. [8, 11] However, all of these occasions have taken place in more developed countries under similar climatic and site specific conditions, which are considerably different from those in developing countries. Population densities in urban areas of developing countries can be up to three times higher than densities in cities of more industrialized countries. [5] Combined with high vulnerabilities, the urban environment in developing countries has specific needs for climate adaptation. [17] Additionally, sustainable development challenges will be increasingly concentrated in cities of lower-middle-income countries as these locations have the greatest speed of urbanization. [4]

Although the Adaptation Support Tool currently does consider some local conditions -soil type, area slope, scale, type of space and subsurface availability- other site specific conditions and criteria are not considered. Thus, the grey, blue and green measures recommended by the tool are often less applicable to urban areas in developing countries than to those in developed countries. Additionally, the AST does not take into account different climatic conditions, whereas climate characteristics could affect the performance and effectiveness. [16] To improve the performance of the tool, additional selection criteria based on local conditions in developing countries and climate specific conditions could be included.

1.3. Objective

The focus of this research is on the inclusion of additional selection criteria in the Adaptation Support Tool, to improve the selection of adaptation measures and the corresponding effectiveness, based on different circumstances in developing countries and different climatic conditions. To achieve this goal, the following research question has been answered:

"How can the Adaptation Support Tool take into account additional criteria to improve the selection of adaptation measures based on different circumstances in developing countries and different climatic conditions during the decision-making process in climate adaptation of the urban environment?"

To answer this research question, multiple sub-questions have been answered:

- Which criteria are applicable to select adaptation measures based on different circumstances in developing countries and different climatic conditions?
- How can the different selection criteria be applied to the grey, blue and green adaptation measures of the Adaptation Support Tool?
- How can the additional selection criteria be programmed into the Adaptation Support Tool?

This research has produced several additional criteria for the selection of adaptation measures to be included in the Adaptation Support Tool, allowing users to set different filters for the selection of adaptation measures. This should support the decision-making process in climate adaptation of the urban environment, as the applicability of the adaptation measures to specific climatic conditions and urban circumstances is improved.

1.4. Method

Several steps were taken to answer the research questions and to improve the Adaptation Support Tool by including additional criteria for the selection of applicable adaptation measures. A visualization of these steps and the entire research process is given by figure 1.1.

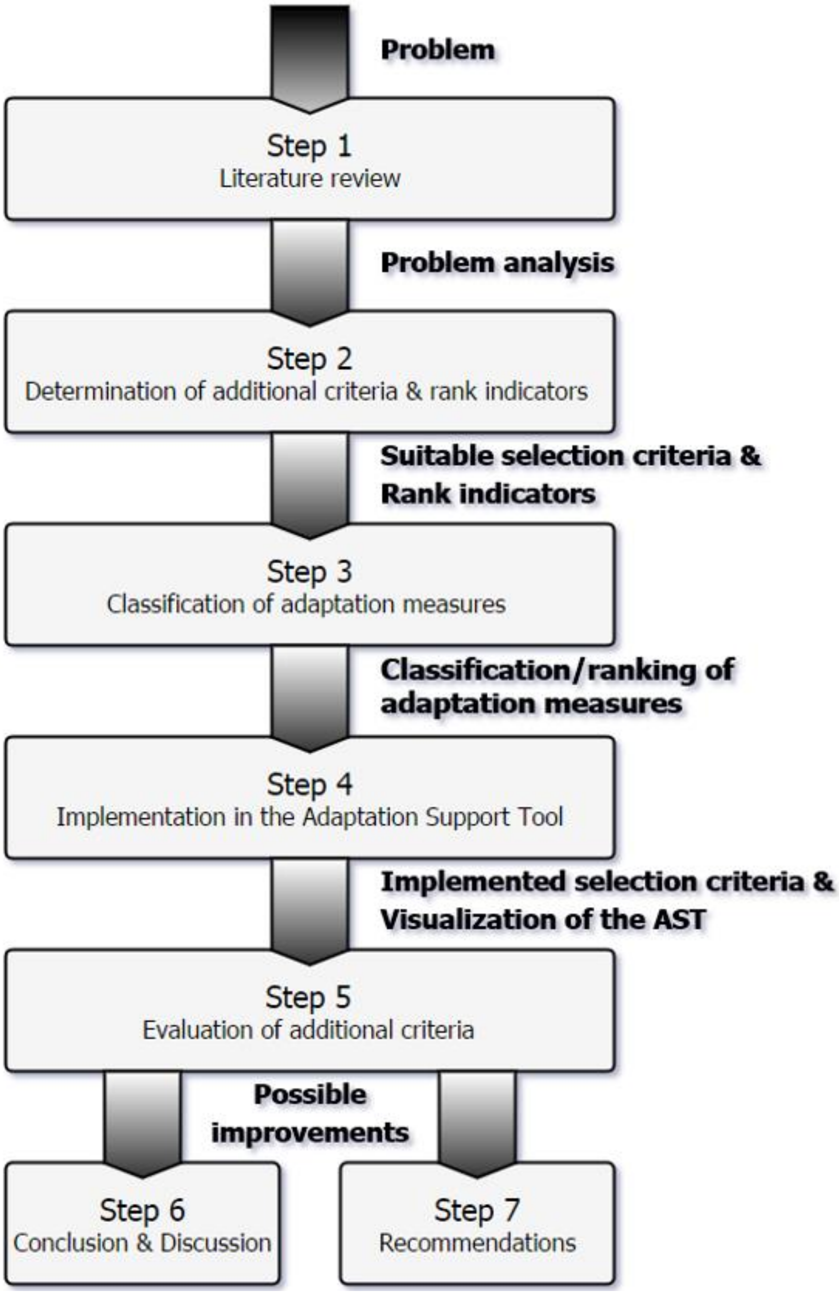


Figure 1.1: Visualization of the research process

The starting point of this research was the problem definition as defined in paragraph two. An extensive literature review was conducted to analyze the problem and to get a better understanding of the issues regarding climate adaptation of the urban environment in developing countries and the effect of different climatic conditions. The results of this literature review have given an overview of those different obstacles and have served as a guideline for the next steps in the research process.

Several selection criteria applicable in developing countries were determined based on a smaller literature research and the characteristics of the adaptation measures currently present in the Adaptation Support Tool. Consequently, suitable ranking indicators necessary for the implementation of the selection criteria in the AST were also determined. The results consisted of an overview of suitable selection criteria and an explanation on selection categories and feasibility ranks which were used to differentiate between the effectiveness of adaptation measures.

The following step was to classify the adaptation measures based on these selection categories and the feasibility ranking. This was mainly achieved by studying the characteristics of the different measures in the tool and conducting additional surveys where necessary. The output of this step was the actual classification or ranking of the adaptation measures.

These results were then used for the calculations of the effectiveness of the measures and the implementation of these calculations in the Adaptation Support Tool. Additionally, a visualization of the tool was given in which the additional selection criteria were included.

The next step of the research was to evaluate the performance of the additional selection criteria, which was done based on virtual case studies of two cities in developing countries. As a result, the performance of the additional selection criteria has been commented on and possible improvements have been given. Hence, the final steps of the research process were to draw conclusions about the results and discuss these. Additionally, several recommendations were given for future improvements of the Adaptation Support Tool.

1.5. Thesis outline

The next chapter of this thesis will give an overview of the most important results of the literature survey concerning the issues regarding climate adaptation of the urban environment in developing countries and the effect of different climatic conditions, which has been used as the basis of this thesis. In the third chapter the additional selection criteria to be implemented in the tool will be presented, based on existing literature and the adaptation measures currently present in the AST. Following, the fourth chapter will elaborate on the ranking indicators that have been used to reflect the feasibility of the adaptation measures in the tool. Based on these ranking indicators, chapter five discusses the actual ranking of the adaptation measures. In chapter six the implementation of the additional selection criteria in the AST is discussed, consisting of both the calculations and the visual presentation. The evaluation of the tool with the inclusion of the additional criteria will be discussed in chapter seven, followed by the conclusion and discussion of the results, and recommendations for future research to improve the performance of the AST.

2. Literature review

To analyze the problem and to get a better understanding of the issues regarding climate adaptation of the urban environment in developing countries and the effect of different climatic conditions, an extensive literature review has been conducted. This review illustrates the necessity of climate adaptation in developing countries, the importance of climatic conditions, and the associated urban planning process. Based on this information the review also elaborates on the Planning Support Systems currently available and the Adaptation Support Tool itself. Together these subjects form the basis of this research and are referred to throughout the thesis.

2.1. Developing countries and climate adaptation

The adaptation of the urban environment as a result of climate change is receiving increasing international attention and the confidence in subsequent climate adaptation projects is growing simultaneously. Although many developing countries have access to sufficient information and knowledge on strategies to implement adaptation measures [18], those countries do have specific needs for adaptation, as the effects of climate change are more severe in developing countries than in developed countries. [17] This is partly caused by the intensification of the physical impacts of climate change in developing countries because, for example, an increasing temperature could lead to higher evaporation losses whereas precipitation is not likely to increase proportionately in those regions. [1] Additionally, the financial and technological capacity of these countries to implement adaptation measures is often limited. [18] Cities in developing countries often lack natural resources, infrastructure, expertise, a strong government system, and the implementation of long-term urban development plans. [17, 19, 20, 21]

Population densities in urban areas of developing countries can be up to three times higher than densities in cities of more industrialized countries. [5] Moreover, sustainable development challenges will be increasingly concentrated in cities of lower-middle-income countries as these locations have the greatest speed of urbanization. [4] A high number of poor people are most likely to be living in low-lying areas, in ravines, on steep slopes and in other risk prone areas. [19, 22] They have less capacity to take measures and suffer greater costs than the wealthier people. [23] Hence, the people with the least capacity to adopt to the effects of climate change are the most vulnerable to its impacts. [20, 24]

According to the IPCC, effective or efficient measures to adapt to climate change are not often taken autonomously. [25] Thus, collaboration is necessary to increase the adaptation capacity of an urban environment without shifting towards maladaptation or becoming more vulnerable. [24] Cities are dynamic systems with unique characteristics, and therefore their adaptation should be location specific and adjusted to local circumstances. [22] However, climate adaptation should not be considered as a stand-alone project, but the risks of climate change should be integrated in urban development programs to emphasize the adjacent opportunities and co-benefits. [11, 17] Additionally, for developing countries it is more cost effective to prevent disasters due to climate change than to recover from them. [23] According to the World Bank, “one dollar of prevention today can avoid as much as four dollars of post-disaster reconstruction expenditure in the future.” [22] Consequently, future adaptation should focus on increasing the robustness of the urban environment, but also on improving the economic and social welfare of individuals and communities. [25] Thus, the integration of climate adaptation plans with urban development plans and policies will be critical. [18, 19, 20]

2.2. Climatic conditions and climate adaptation

Besides the relationship between climate adaptation and developing countries, another important connection is found between climate adaptation and the climatic conditions of the urban environment that is subject to adaptation. [26] The effects of climate change on this environment will depend on the actual climatic conditions which will have a different spatial distribution. [22] Hence, urban climate information is critical for urban planning, and adequate measures vary according to the climate of the urban area. [27] Different climatic conditions could have a large impact on the effectiveness and the performance of the adaptation measures, and as such it is important to include these climatic conditions in the Adaptation Support Tool. [16] The most widely used system for classifying the world's climate types is the Köppen Climate Classification System, developed by Wladimir Köppen in 1900. This system divides the world into different categories based on the annual and monthly averages of precipitation and temperature, creating five major climate types indicated by a capital letter: equatorial climates (A), arid climates (B), temperate climates (C), continental climates (D), and polar climates (E). [26]

Equatorial climates (A) are characterized by an average temperature larger than 18° Celsius in every month, and an annual precipitation of more than 1500 mm. These climates extend northward and southward from the equator to about 20° latitude. Extending further in both directions from 20° to 35° latitude, the arid climates (B) can be found, often surrounded by mountains. The most important feature for this climate is that the potential evaporation and transpiration exceed the precipitation. The temperate climates (C) generally have warm and humid summers and mild winters, with temperatures ranging between -3° Celsius and 18° Celsius. This climate extents from 30° to 50° latitude and is characterized by the presence of cyclones during the winter, and thunderstorms during the summer period. Moving further away from the equator towards the poles, the continental climates (D) have warm to cool summers and cold winters, the latter characterized by strong winds and snowstorms. The monthly average temperature of the coldest month is less than -3° Celsius, whereas the average temperature of the warmest month is greater than 10° Celsius. The polar climates (E) are found on the northern coastal areas of North America, Asia, Europe, Antarctica and Greenland. These areas are faced with cold temperatures during the whole year, with the average temperature of the warmest month being less than 10° Celsius. [26, 28]

Although more climatic subcategories are defined within the Köppen Climate Classification System, these have not been implemented in the AST. The characteristics of these subcategories are too extensive compared to the data input of the tool, and could potentially overcomplicate the selection process of the adaptation measures of the AST.

2.3. Urban planning

In the previous chapters the possibilities for the adaptation of the urban environment have been discussed, accompanied by two critical relationships between developing countries and climatic conditions, and climate adaptation. These possibilities consist of the implementation of either grey, blue or green measures. However, the most difficult part of this process is not to determine the different measures, but to implement those in the urban environment.
Because of the possible hazards caused by climate change as described in paragraph 1.1.2., it can be decided to include climate adaptation measures into the urban planning process (figure 2.1). However, most cities are already densely built leaving few options to implement adaptation measures without significant changes to the environment. Fortunately, constant changes to the urban environment are being made as a result of the dynamic character of existing cities to maintain, modify and renew areas. This dynamic behavior creates the opportunities to implement the measures and include these in the urban planning process. [16]
Urban planning exists of multiple consecutive phases starting with the research and analysis, during which the urban system is analyzed and the problem is defined. Followed by the program development, these components cover the initiative phase of the urban planning process. Consecutively, the design phase is started in which the conceptual, preliminary and final designs are created, based on the analysis of the previous phase. During this phase the implementation of these designs is also described, concluding the design phase. The urban planning process ends with a final decision about an urban adaptation plan. Although urban planning is shown as a stepwise and straightforward process, in practice it often reiterates to an earlier stage in the process to examine different adaptation possibilities. [8, 11] Thus, urban planning is an instrument used for coordination and communication, often being the starting point for discussions between stakeholders with different interests and goals. [29]

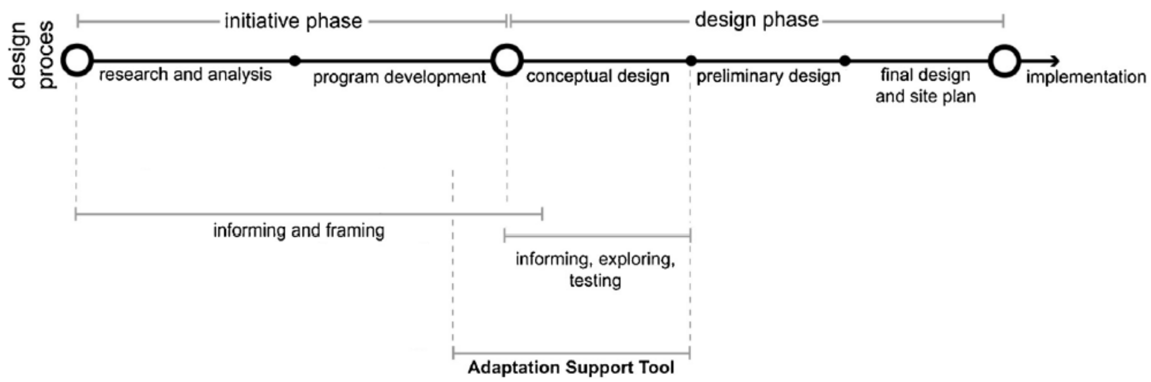


Figure 2.1: Visual representation of the urban planning process [8]

In developing countries, national governments often establish regional authorities to plan the investments in the urban environment. However, these authorities currently do not extensively follow regional land use planning goals, community input or the needs of poor communities. Local land use plans and regulations are not adequately considered, and non-governmental organizations are not incorporated into the government's urban planning process. Additional obstacles to efficient urban planning in developing countries include the limited public resources, conflicting political motivations, and the weak capacity for planning on a regional level. Nevertheless, developing countries are starting to develop national strategies for urban planning and climate change. Within those strategies it is important that a diagnostic tool is developed to assess and improve urban planning. [24, 30] Municipal governments should engage with representatives of all income groups and incorporate local knowledge to implement adequate climate adaptation measures, rather than enforce the national adaptation strategies. [17, 21, 22, 31] Better aligned visions between ministries, governments, institutions and non-governmental organizations, and the integration of climate change in the process of urban planning result in more realistic, efficient and implementable climate adaptation plans. [18, 29]

2.4. Planning Support Systems

As urban planning is a complex process involving many different stakeholders, guidance is required to facilitate the implementation of grey, blue and green adaptation measures, and to evaluate the applicability of these measures for a specific project location. [16, 32] Although several tools exist for the planning of adaptation measures [33, 34], the urban planning process is not incorporated in most of these tools. However, to make a reliable decision on an attractive and effective set of adaptation measures, insight in the effect of each of those measures on the project area is required. [16] Hence, the purpose of planning support systems (PSS) is not only to structure and improve planning processes and make them more interactive and participatory, but also to improve the outcomes of these processes "by providing relevant knowledge and facilitating a design-analysis loop that improves the link between explicit knowledge and planning actions". [34] The initial planning support systems mainly focus on the instrument rather than on the usage and the urban context. [35] These systems do not provide support in the selection process and design of spatial interventions, nor do they provide a method of evaluation on the effect of adaptation measures regarding climate change. [16]

2.5. Adaptation Support Tool

As a response to the lack of planning support systems that support participatory design, the Adaptation Support Tool (AST) has been developed by Deltares to offer support during the urban planning process. This tool was developed to fill the gap left by the many tools that address the need for adaptation on a policy-level and to assess the vulnerability of the urban environment, and the ability to implement adaptation measures in the actual urban planning and design processes. [8]

2.5.1. Background

The Adaptation Support Tool was developed as a tool to "support during the conceptual planning processes of stakeholders in their efforts to make the urban area more resilient to climate change". [8] The AST allows stakeholders to define their program of demands, their adaptation targets and several environmental parameters characteristic for the project location. This map-based tool facilitates the evaluation of more than 65 grey, blue and green adaptation measures for a specific urban location, by quantifying the costs, effectiveness regarding climate resilience, water quality, and potential co-benefits for each of those measures. [11, 36] This information is crucial for the decision on where and how certain adaptation measures can be applied such that a co-created conceptual design plan is formed.

2.5.2. Operation

The Adaptation Support Tool incorporates a total of 66 adaptation measures to adapt the urban environment to pluvial flooding, droughts and heat stress. These measures can be divided into either grey, green or blue measures, or a combination of those. Although traditional grey measures are included in the tool, the emphasis is on the blue and green measures, because these measures incorporate natural and semi-natural processes and spaces, utilize underlying ecosystem function and generate other social, cultural and economic co-benefits. [11, 16]

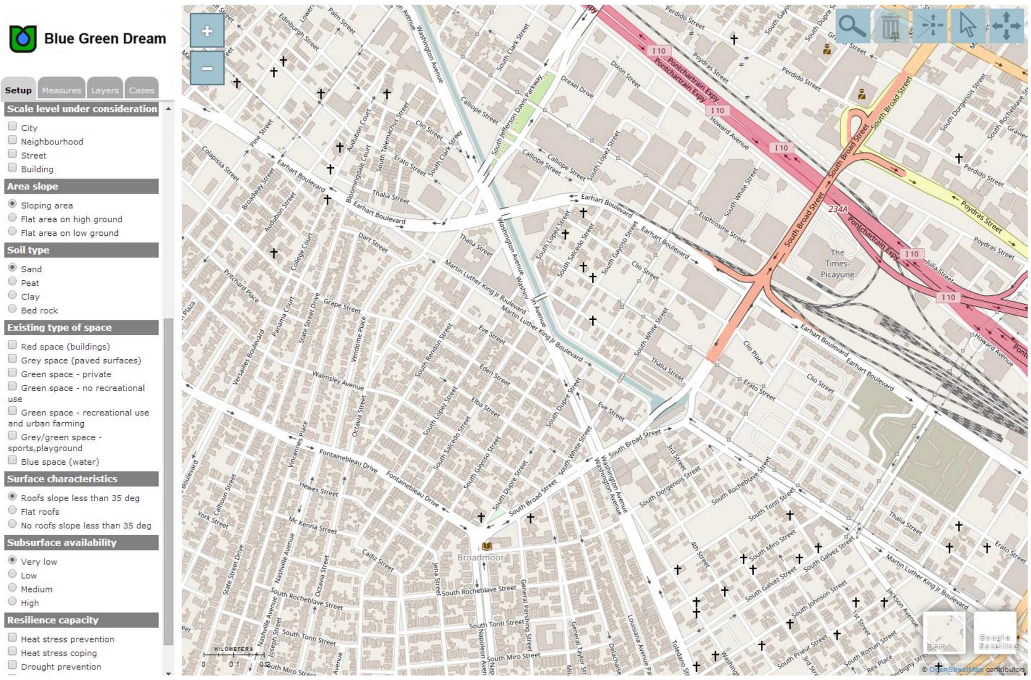
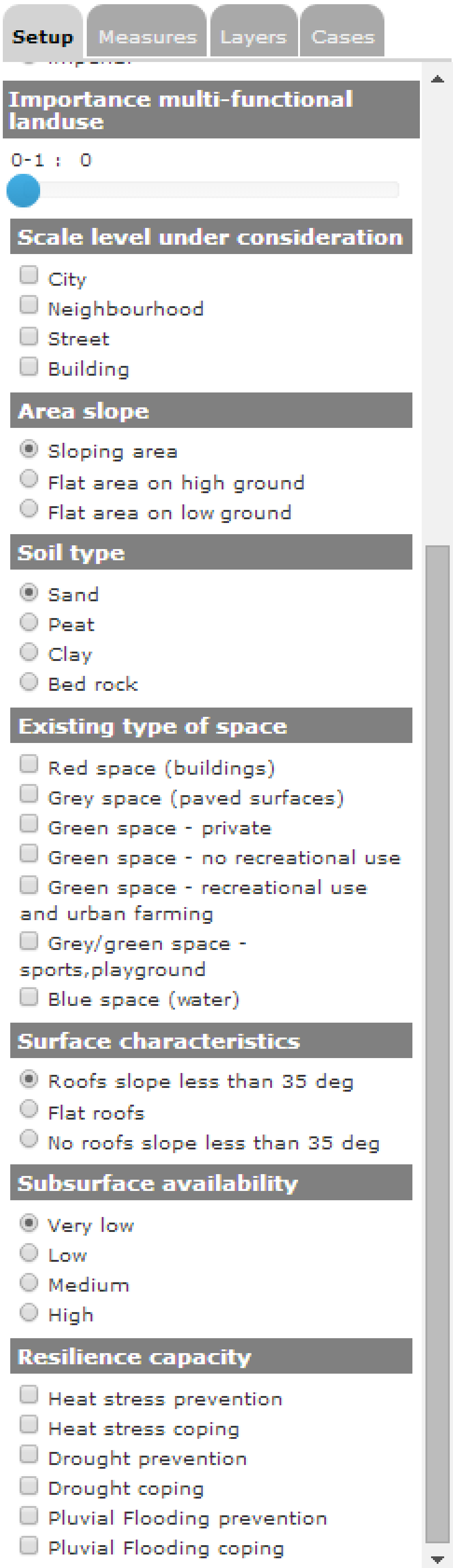
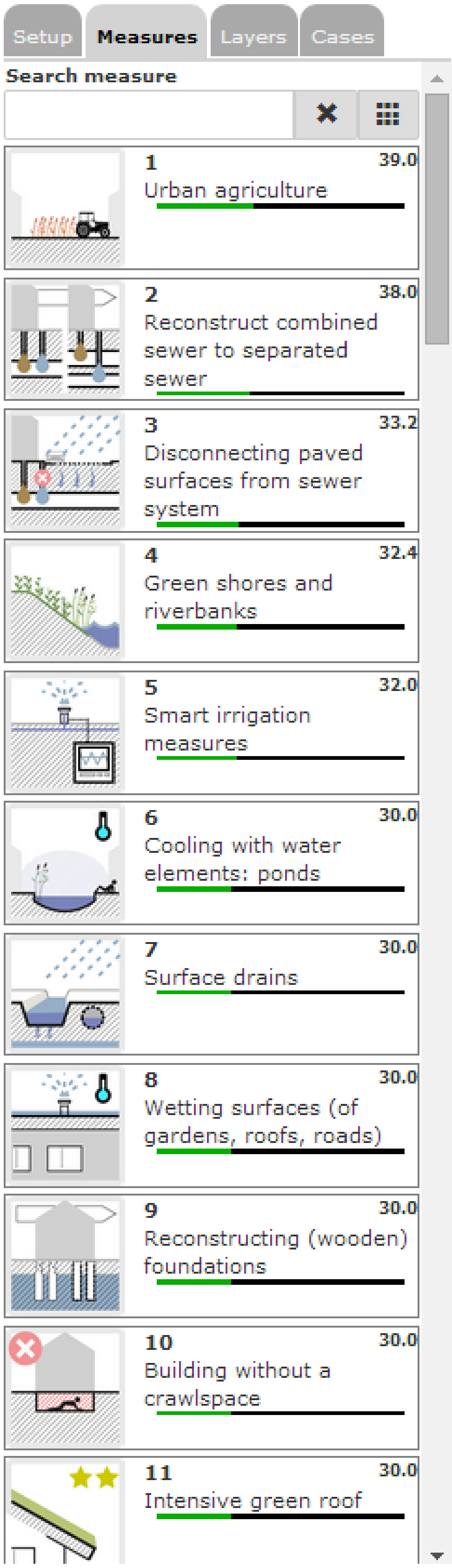


Figure 2.2: Overview of the Adaptation Support Tool

An overview of the tool is given in figure 2.2, representing the three main panels of the AST: left, center and right. The left panel (figure 2.3.a) provides information about the characteristics of the project area, which can be set by the user: environmental characteristics, characteristics of the urban built form, and the spatial scale. More specifically, information can be entered regarding the size and location of the considered project area, the importance of multifunctional land use, the scale level under consideration, the slope of the area, the soil type, the existing type of space, surface characteristics, the subsurface availability, and the adaptation targets (resilience capacity). [16] Based on these characteristics the feasibility of every adaptation measure is calculated and ranked, which is then presented in a ranked list of adaptation measures (figure 2.3.b). Each measure includes additional information about the specific measure itself, consisting of a visual representation and an explanation of the measure. A ranked overview of several adaptation measures is also readily available to its users (figure 2.4). This overview allows users to easily explore different options and select a preferred measure to adapt the urban environment to climate change. Similar to the ranked list of measures, each measure in this overview includes additional information about the specific measure itself.



(a) Information about the project area characteristics



(b) Ranked list of adaptation measures

Figure 2.3: Left panel of the Adaptation Support Tool

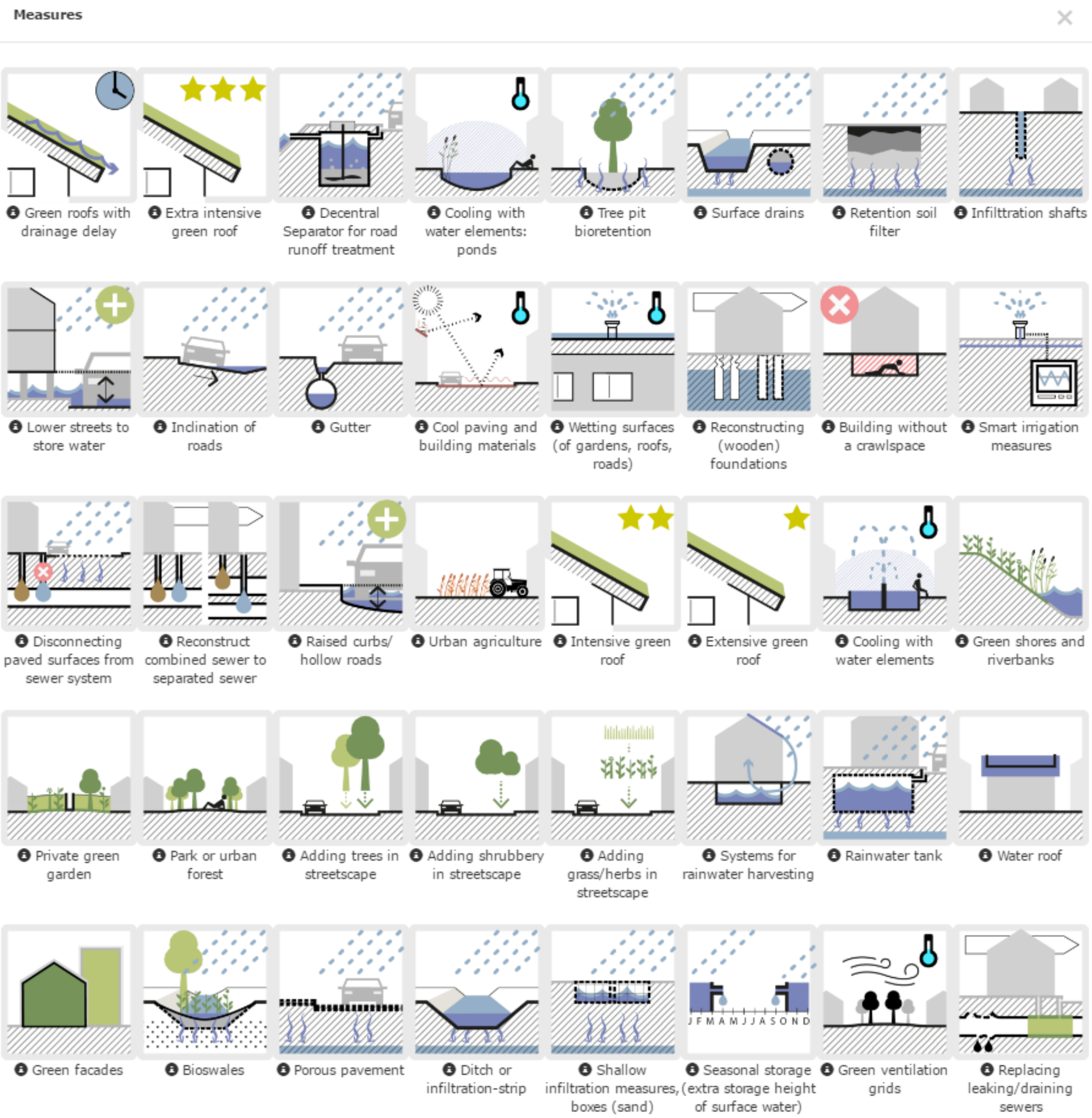
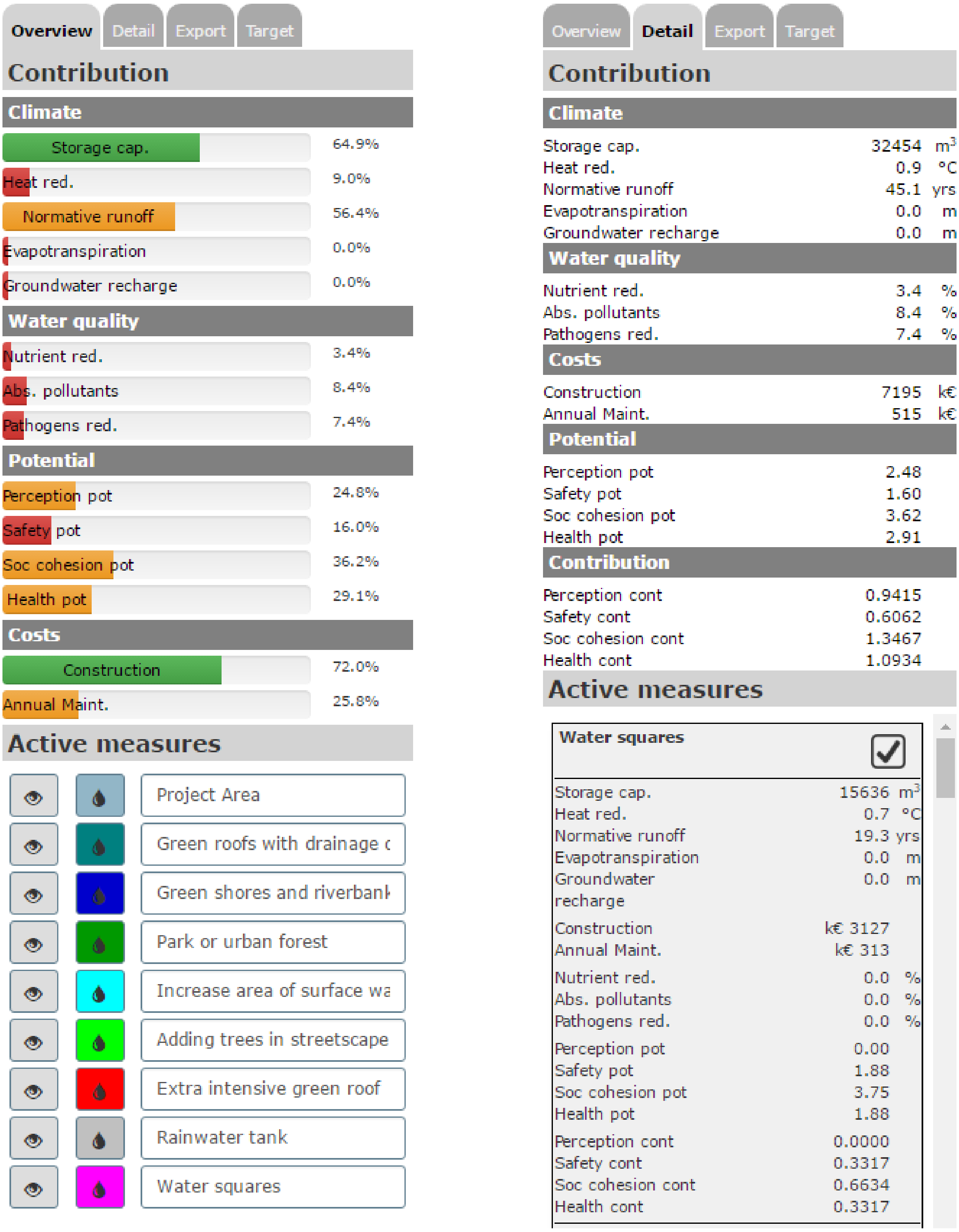


Figure 2.4: Overview of several adaptation measures

The center panel is the drawing area of the tool, in which the size and location of the project area can be drawn (figure 2.5). The user can determine the size of adaptation measures and subsequently draw these within the boundaries of the project area. A configuration tool allows users to customize the dimensions of the measures. Multiple layers, including the default Google Earth and OpenStreetMap layers, can be shown providing a clear overview and comparison of different project areas and adaptation measures.

Figure 2.5: Center panel of the Adaptation Support Tool



(a) Overview of the performance of adaptation measures

(b) Quantitative details of adaptation measures

Figure 2.6: Right panel of the Adaptation Support Tool

The right panel consists of multiple tabs, of which the first (figure 2.6.a) gives an overview of the performance of the adaptation measures in terms of climate (storage capacity, heat stress reduction, normative runoff, evapotranspiration and groundwater recharge), water quality (nutrients reduction, absorbed pollutants and pathogens reduction), potential co-benefits (perception, safety, social cohesion and health) and costs (construction and maintenance). The overview presents the results in a percentage of the adaptation targets, which can be determined by the user in the target tab. This qualitative representation of the results allows for a quick overview of the effectiveness of the selected adaptation measures. A more quantitative approach to the effectiveness of the measures is given in the detail tab (figure 2.6.b), which also provides information on the contribution of each single measure and the associated costs.

2.5.3. Performance

The Adaptation Support Tool has been used in numerous cases and has shown its added value in the urban planning process. [8, 11] However, these occasions have mostly taken place in more developed countries under similar climatic and site specific conditions. Not only do developing countries have considerably different site specific conditions compared to developed countries [19], climatic conditions are also highly variable around the globe. [26] Although the AST currently does consider several characteristics of the project area -soil type, area slope, scale, type of space and subsurface availability- other site specific conditions and criteria are not considered. Thus, the currently recommended grey, blue and green measures might be less applicable to urban areas in developing countries than to those in developed countries. Additionally, the AST does not consider different climatic conditions, whereas climate characteristics could affect the performance and effectiveness of adaptation measures. [16]

3. Additional selection criteria

As a result of the literature survey conducted to better understand the relationships between climate adaptation, developing countries and climatic conditions, multiple additional selection criteria have been distinguished to include in the Adaptation Support Tool to improve its usefulness. However, the number of additional criteria that can be included in the tool is limited.

3.1. Number of additional criteria

The amount of information an individual can process at any given moment in time is limited, and including more information than this limit could lead to an overload of information being harmful for the decision-making process. [37] Similarly, people face difficulties making decisions when many equivalent choices are available. Many potential outcomes and risks as a result of the wrong choice could be overwhelming for the decision-making process. [38] Up to a certain amount more choices lead to more satisfaction, but with an increasing number of choices people tend to experience more confusion and dissatisfaction with their choices. Hence, whereas initially a large amount of choices could be appealing, a smaller amount of choices leads to increased satisfaction. [39] The limit on the amount of information and choices that can be processed is limited by three different processes [37]:

- The span of absolute judgement describes the limit in the magnitude of variables a person can identify. Usually, this limit is somewhere around seven variables, but several techniques are available to increase this span and thereby increase the satisfaction of the choices. Increasing the number of dimensions along which the variables differ, arranging the judgements into a sequence of absolute judgements, and making a relative instead of an absolute judgement could increase the accuracy of choices.
- The span of immediate memory is the limit in the magnitude of successive judgements of a person, and thereby limits the increase in the span of absolute judgement by creating a sequence of judgements. Similar to the span of absolute judgement, this span is about seven items in length, but is caused by a different process. Whereas the limit of the span of absolute judgement relates to variables, the span of immediate memory is about items, which could also include groups of variables or other groups of information. Thus, the span of immediate memory could include more than seven variables.
- The span of attention describes the limit in the magnitude of items a person can distinguish in a single moment in time. As this limit is somewhere around six variables, presenting a larger number of items will create a situation that cannot be understood at a glance.

Because of these processes, the maximum amount of selection criteria that could have been presented in the Adaptation Support Tool is limited to roughly six or seven. Implementing a larger amount of selection criteria would have limited the comprehension of the information in the AST, and thus would not necessarily have increased the performance of the tool. Additionally, even by increasing the span of absolute judgement, the limits imposed by the span of immediate memory and attention were still applicable and therefore have been taken into account.

3.2. Choice of additional criteria

The conducted literature survey (chapter 2) has revealed some of the most important issues related to climate adaptation in developing countries. Combined with the information about the adaptation measures currently present in the AST, several additional selection criteria have been distinguished that could improve the selection of adaptation measures (figure 3.1).

Number	Possible selection criteria
1	Climatic conditions
2	Existing infrastructure
3	Governance
4	Natural resources
5	Policies
6	Preferred construction costs
7	Preferred maintenance
8	Preferred technological complexity
9	Presence of solid waste
10	Urban development plans

Figure 3.1: List of possible selection criteria

However, the information presented in the tool must be useful for the users and quantifiable for the ranking procedure of the adaptation measures. Additionally, the total amount of selection criteria that can be presented without confusion or the loss of information is limited, because of the limits on information processing and decision making.

The lack of a clear governance system, policies, and long-term urban development plans does complicate the process of climate adaptation in urban areas. The existence of long-term urban development plans is important for the life-expectancy of the adaptation measures, as the construction costs of these measures can be substantial and thus certainty about the zoning plan is required. Similarly, the lack of a strong government and policies in urban planning and adaptation complicates the urban planning process. However, these issues are not fit for implementation in the Adaptation Support Tool, as they are hard to quantify and should be addressed during the discussion following from the results of the AST, or in another stage of the urban planning process. Also, the availability of natural resources has a large impact on the economic development of developing countries [40], but does not have a clear relation with adaptation measures applied to the urban environment. Hence, only a specific selection of the criteria is included in the Adaptation Support Tool (figure 3.2).

Number	Applicable selection criteria
1	Climatic conditions
2	Existing infrastructure
3	Preferred construction costs
4	Preferred maintenance
5	Preferred technological complexity
6	Presence of solid waste

Figure 3.2: List of applicable selection criteria

3.2.1. Climatic conditions

The effects of climate change on the urban environment depend on the actual climatic conditions of those areas, and therefore urban climate information is critical for the implementation of climate adaptation measures. As adequate measures vary depending on the climate, different climatic conditions have a large impact on the effectiveness of those measures. [16, 22, 26] For example, the implementation of green roofs as a measure to reduce drought and flood hazards in the urban environment is less applicable in areas with temperatures below the freezing point.

The Köppen Climate Classification System divides the world into different categories based on the annual and monthly averages of precipitation and temperature. Hence, the effectiveness of the adaptation measures is based on these characteristics, taking into account the major climatic categories as composed by Wladimir Köppen.

3.2.2. Existing infrastructure

Many cities in developing countries are faced with multiple challenges, including a lack of adequate infrastructure. [17, 19, 20, 21] Inadequate infrastructure is considered one of the barriers that limits sustainable development and limits resilience to climate disasters and variability. [22] The importance of infrastructure to growth and thus to climate adaptation is great as a better quantity and quality of infrastructure can directly raise the productivity of multiple processes in the urban environment. [41]

More specifically, the adaptation measures included in the AST are significantly influenced by the existence of proper infrastructure. In general, infrastructure is defined as electricity, gas, telecoms, transport and water supply, and sewerage. [41] Due to the characteristics of the adaptation measures, the existence of transport networks (roads), water supply networks and sewerage have been considered the most important components of the infrastructure to be included in the Adaptation Support Tool. For example, increasing the capacity of the sewer system is not applicable to an urban environment lacking such a system.

3.2.3. Preferred construction costs

The implementation of adaptation measures is strongly related to the construction costs of those measures. [20] Construction costs are the expenses incurred by a contractor for the implementation of an adaptation measure. However, the financial capacity of developing countries to implement adaptation measures is often limited. [18] Thus, external funding is often required to realize the implementation of these measures in the urban landscape. [23] Consequently, the costs of the adaptation measures are an important aspect of the climate adaptation procedure.

Currently, the Adaptation Support Tool does already include the costs for the construction of most of the grey, blue and green measures. However, these costs are presented in the overview and detail tab (figure 2.6), which is only accessible as output information to the user. Because of the importance of the financial capacity of developing countries, the construction costs have been more specifically implemented in the Adaptation Support Tool. The effectiveness of these measures is based on the relative costs of the adaptation measures.

3.2.4. Preferred maintenance

In most developing countries, maintenance is often seen as an unimportant activity and is not given a high priority. As a result, it has become one of the most faced issues by organizations in those countries. [42] Consequently, it is important to address the preferred maintenance of the adaptation measures as this could have a large impact on the feasibility of the measures. Maintenance is defined as the process of maintaining or improving the state of an adaptation measure. This translates into the ease and speed with which an adaptation measure can be restored to or kept at operational status.

Similar to the visualization of the construction costs, the Adaptation Support Tool does include maintenance costs but only presents this information as output to the user. Because of the importance of maintenance in developing countries, this criterion has been more specifically implemented in the Adaptation Support Tool. The effectiveness of the adaptation measures is based on the necessary maintenance of the measure.

3.2.5. Preferred technological complexity

Technology plays an important role in the adaptation of the urban environment to climate change, as most methods of adaptation involve some form of technology. [43] Solutions such as desalination technologies and efficient cooling systems can lead to a more resilient city under the conditions of climate change. [44] The development of new technologies, and the redevelopment of existing technologies are important aspects of climate adaptation [45]. Technology does not just include materials, equipment or resources, but also consists of multiple forms of knowledge. In developing countries, local knowledge is an important factor in the climate adaptation process, as this not only improves maintenance but also encourages involvement in climate adaptation projects.

Although the forms of technology for adaptation are often fairly familiar [43], the technical complexity varies between different adaptation measures. For example, the implementation of an infiltration field is not as complex as installing a green roof. As local knowledge, materials and resources may be limited, some adaptation measures that are characterized by a relatively high technological complexity may therefore be less applicable as measures to reduce the impacts of climate change. Hence, technological complexity has a strong relation with the implementation of adaptation measures and has been included in the Adaptation Support Tool.

3.2.6. Presence of solid waste

Solid waste originates from a variety of sources, with material types including electronics, plastics, glass, human fecal matter, metals, and other hazardous materials. The systems to dispose of solid waste are often logistically complicated and costly, and as developing cities grow, it can be complicated to develop suitable collection and disposal systems. [22] Thus, solid waste disposal systems in developing countries are often inadequate or nonexistent. This leads to the presence of solid waste in waterways, canals, and other water runoff or flood control designated areas. [46] Not only can areas of uncollected waste increase the threats of health hazards and environmental pollution, it also increases the vulnerability of the urban environment to floods from intense precipitation. [22] For example, a gutter is only an effective measure to collect and transport water if the gutter is mostly free from solid waste due to possible blocking. Hence, the existence of solid waste has a large influence on the effectiveness of adaptation measures to adapt an urban area to climate change and has been considered an important selection criterion to be included in the Adaptation Support Tool.

4. Rank indicators

Each of the additional selection criteria have been divided into multiple categories, to allow for the ranking of the climate adaptation measures based on these selection categories. An overall feasibility ranking was then used to rank the feasibility of the adaptation measures for different circumstances.

4.1. Ranking categories

The six additional selection criteria have been used to provide an additional ranking to the adaptation measures currently present in the Adaptation Support Tool. Each of these criteria has been divided into multiple categories based on their important aspects as discussed in the previous chapter.

Consequentially, the selection criterion of climatic conditions has been divided into five different climate categories, based on the annual and monthly averages of precipitation and temperature. These categories are similar to the five categories of the Köppen Climate Classification System. Hence, the selection criterion of climatic conditions has been divided into equatorial, arid, temperate, continental, and polar climates (figure 4.1).

Climatic conditions
Equatorial climate
Arid climate
Temperate climate
Continental climate
Polar climate

Figure 4.1: Ranking categories of the climatic conditions selection criterion

The selection criterion of infrastructure focusses on the level of existing infrastructure in the urban environment. Due to the characteristics of the adaptation measures, roads, water supply networks and sewerage are the most important components of the existing infrastructure. Hence, these three types of existing infrastructure have been used to establish the different categories of this selection criterion (figure 4.2).

Existing infrastructure
Roads
Water supply networks
Sewerage

Figure 4.2: Ranking categories of the existing infrastructure selection criterion

Thirdly, the selection criterion of preferred construction costs has been divided into three different categories, based on the relative costs of the implementation of the adaptation measures. Currently the Adaptation Support Tool does already include quantitative construction costs as output, presented as the costs per m^2 of space required for each adaptation measure. Hence, these figures have been used to derive the relative construction costs used to define the categories of this selection criterion. Because a visualization of relative construction costs is sufficient in the middle stages of urban planning, these categories have been defined as adaptation measures that have relatively low, medium, and high construction costs (figure 4.3).

Preferred construction costs
Low
Medium
High

Figure 4.3: Ranking categories of the preferred construction costs selection criterion

The selection criterion of preferred maintenance has been divided into three different categories, based on the amount of required maintenance to maintain or improve the state of an adaptation measure. The Adaptation Support Tool currently includes maintenance as output, expressed as the maintenance costs, which is defined as the annual percentage of the total construction costs. It was assumed that this expression of the maintenance costs could be considered as an expression for the necessary maintenance. As a visual representation of the maintenance is sufficient in the conceptual design phase of the urban planning process, the categories of this selection criteria have been defined as adaptation measures characterized by a relatively low, medium, and high amount of maintenance (figure 4.4).

Preferred maintenance
Low
Medium
High

Figure 4.4: Ranking categories of the preferred maintenance selection criterion

The selection criterion of preferred technological complexity has been divided into three different categories, representing the complexity of the adaptation measures, in terms of both materials, resources and knowledge. As the technological complexity differs between adaptation measures, this selection criterion has also been divided into categories representing this division. These categories have been defined as adaptation measures that have a relatively low, medium, and high technological complexity (figure 4.5).

Preferred technological complexity
Low
Medium
High

Figure 4.5: Ranking categories of the preferred technological complexity selection criterion

The selection criterion of solid waste focusses on the presence of solid waste in the urban environment. As the amount of solid waste has a large influence on the effectiveness of adaptation measures to adapt an urban area to climate change, this selection criterion has been divided into three different categories. These categories represent the relative amount of solid waste present in an area, defined as areas with a relatively low, medium, and high amount of solid waste (figure 4.6). As an urban environment without any form of solid waste practically does not exist, a category representing the absence of solid waste has not been included. Thus, the category with a relatively low amount of solid waste represents an area with the least amount of solid waste present.

Presence of solid waste
Low
Medium
High

Figure 4.6: Ranking categories of the presence of solid waste selection criterion

4.2. Feasibility ranking

The feasibility of the adaptation measures under different circumstances has been ranked based on a feasibility ranking, which has been applied to each of the aforementioned selection categories. The scores used to produce this ranking have been based on the scores that are already included in the Adaptation Support Tool. As the additional selection criteria are of the same level of importance as the existing criteria, the adaptation measures have been scored with integer values similar to the existing figures. [36] Hence, the integer values of 0 (zero), 4 (four), 7 (seven), and 10 (ten) have been used, depending on the level of feasibility of the measures for each selection criterion (figure 4.7). This range has made it possible to assign relative feasibility scores with distinct differentiation between different levels of feasibility.

Feasibility score	**Feasibility**
0	No feasibility
4	Low feasibility
7	Moderate feasibility
10	High feasibility

Figure 4.7: Feasibility ranking of the adaptation measures for the additional selection criteria

Based on these scores, each adaptation measure has been ranked for every category of the additional selection criteria. For example, a certain measure could score a four on feasibility concerning a large presence of solid waste, a seven for moderate presence, and a ten for a small presence of solid waste, illustrating that this measure is less feasible in urban environments with a large amount of solid waste.

5. Classification of measures

The feasibility ranking has been assigned to each of the selection criteria's categories to classify and rank the climate adaptation measures for each of the additional selection criteria. Hence, each measure consists of a different classification of this ranking.

5.1. Climatic conditions

For the selection criterion of climatic conditions, the adaptation measures have been ranked for each of the five selection categories, based upon expert-judgement and the resilience capacity of the measures, the latter already being present in the AST. This resilience capacity (heat stress, droughts and pluvial flooding threshold and coping) has served as the guideline for the feasibility ranking. For each of the climates the importance of these capacities is different, which resulted in a different feasibility rank for every measure and climate. Moreover, expert-judgement has been used to determine which measures are not feasible in different climates, as certain climatic conditions strongly influence the implementation capability of several measures.

In arid climates, the implementation capability of measures consisting mostly of green elements is greatly reduced due to the low amounts of precipitation and high amounts of evaporation. Similarly, in polar climates, measures consisting mostly of either green or blue elements are considered extremely difficult to implement, due to the severely low temperatures. Thus, those measures in these climates have been assigned a feasibility score of 0 (no feasibility).

Furthermore, in equatorial climates, the remaining measures aimed at heat stress and pluvial flooding have been considered more important than measures aimed at droughts, due to the abundance of rainfall in these climates. Likewise, in arid climates, heat stress and droughts have been considered more important due to the low amounts of precipitation and high amounts of evaporation. Similarly, in continental climates, measures aimed at droughts and pluvial flooding are more important than measures aimed at heat stress, due to the low temperatures in this climate. In polar climates, measures aimed at pluvial flooding are more important due to the low temperatures and abundance of water. Consequently, a feasibility score of 4 (low feasibility) has been assigned to measures of which the resilience capacities did not correspond to the important capacities of each different climate. A feasibility score of 7 (moderate feasibility) has been assigned to measures of which only one of the capacities di correspond, and a score of 10 (high feasibility) has been assigned to measures of which both capacities did correspond to the resilience capacities. As polar climates are only subject to a single resilience capacity, in polar climates a feasibility score of 4 has been assigned to measures of which the capacities did not correspond to the capacity of pluvial flooding. A feasibility score of 7 has been assigned to measures of which the pluvial flooding only incorporated either threshold of coping abilities, and a score of 10 has been assigned to measures that incorporated both pluvial flooding abilities.

Lastly, no differentiation was made between the different measures for the temperate climate, as every measure is implementable and no clear distinction between the importance of resilience capacities is present. Therefore, the measures for this climate have all been assigned a feasibility score of 10 (high feasibility).

Appendix A.1 presents a list of every adaptation measure and its corresponding feasibility ranking for each selection category.

5.2. Existing infrastructure

For the selection criterion of infrastructure, the adaptation measures have been ranked separately for each of the three categories (roads, water supply network, and sewerage). Each of these categories consists of two sub-groups, indicating either the existence of a certain type of infrastructure (positive), or the lack of this type of infrastructure (negative). The different infrastructure categories have been compared for every measure, resulting in a feasibility rank for every measure and different selection criterion category as defined by chapter 4. Appendix A.2 presents a list of every adaptation measure and its corresponding feasibility ranking for each selection category, which has been mainly based on expert-judgement. For example, green facades are not influenced by the existence of roads or sewerage, and have therefore been assigned a feasibility score of 10 (high feasibility) for both the existence of these types of infrastructure or the lack thereof. However, the lack of a water supply system influences the irrigation availability and thus decreases the feasibility of this measure. Hence, green facades have been assigned a score of 4 (low feasibility) in case a water supply system does not exist, and a score of 10 (high feasibility) if it does.

5.3. Preferred construction costs

Within this selection criterion the adaptation measures have been divided into three different groups, based upon the total construction costs (€/m^2) of these measures. These costs have served as a guideline for the distribution, resulting in three groups of approximately the same amount of adaptation measures. Hence, group “A” consists of measures with construction costs less than 50 €/m^2, group “B” of measures ranging between 50 €/m^2 and 200 €/m^2, and group “C” of measures with costs higher than 200 €/m^2. These groups have been used to determine different ranges of construction costs to which the feasibility ranking has been applied, associating a different amount of construction costs to a different level of feasibility, which corresponded to a selection category as defined by chapter 4. Appendix A.3 presents a list of every adaptation measure and its corresponding costs and feasibility ranking for each selection category.
An overview of this ranking and the selection criterion categories is presented by figure 5.1. Selecting a superlative option also automatically includes the lower degree option(s), as these are still of interest to the users. For example, if users would set the preferred construction costs to “high”, it is assumed that the users are not only interested in measures that have relatively high costs, but are also interested in the measures with relatively low and medium costs.
For example, the construction costs of intensive green roofs are defined as 100 €/m^2, which scores a 4 (low feasibility) in case only adaptation measures with relatively low construction costs are preferred, a 7 (moderate feasibility) for medium costs, and a 10 (high feasibility) for measures up to relatively high construction costs.

		Feasibility ranking			
		0	**4**	**7**	**10**
Selection category	**Low**	> 100	51 - 100	25 - 50	< 25
	Medium	> 400	201 - 400	100 - 200	< 100
	High	-	> 800	400 - 800	< 400

Figure 5.1: Overview of the feasibility ranking for the preferred construction costs selection criterion, with costs in €/m^2

5.4. Preferred maintenance

Similar to the construction costs criterion, within this selection criterion the adaptation measures have also been divided into three different groups, but based upon the total annual maintenance costs (percentage of the construction costs) of these measures. These costs have served as a guideline for the distribution, again resulting in three groups of approximately the same amount of measures. Hence, group "A" consists of measures with annual maintenance costs less than 5% of the construction costs, group "B" of measures ranging between 5% and 10%, and group "C" of measures with annual costs exceeding 10% of the construction costs. Similarly, these groups have been used to determine different ranges of maintenance costs to which the feasibility ranking has been applied, associating a different amount of maintenance costs to a different level of feasibility, which did correspond to a selection category as defined by chapter 4. Appendix A.4 presents a list of every adaptation measure and its corresponding costs and feasibility ranking for each selection category.
An overview of this ranking and the selection criterion categories is presented by figure 5.2. Selecting a superlative option again also automatically includes the lower degree option(s), as these are still of interest to the users. As an example, the annual maintenance costs of intensive green roofs are defined as 5% of the construction costs, which scores a 7 (moderate feasibility) in case only adaptation measures with relatively low maintenance costs are preferred, also a 7 (moderate feasibility) for medium costs, and a 10 (high feasibility) for measures up to relatively high annual maintenance costs.

		Feasibility ranking			
		0	**4**	**7**	**10**
Selection category	**Low**	> 10	6 - 10	3 - 5	< 3
	Medium	> 20	10 - 20	5 - 10	< 5
	High	-	> 40	20 - 40	< 20

Figure 5.2: Overview of the feasibility ranking for the preferred maintenance selection criterion, with numbers in annual percentages of the construction costs

5.5. Preferred technological complexity

Within this selection criterion the adaptation measures have been divided into five different groups, based upon the technological complexity of these measures. Measures with similar levels of complexity have been grouped together in the same group, based on expert-judgement on the complexity of these measures. The first group (group "A") consists of measures that require relatively low levels of technology, which increases with every group, up to the measures of the fifth group (group "E") which require high levels of technology. The feasibility ranking has then been applied to each of these groups, associating a different amount of technological complexity to a different level of feasibility, which did correspond to a different selection criterion category as defined by chapter 4. Appendix A.5 presents a list of every adaptation measure and its corresponding complexity and feasibility ranking for each selection category.

An overview of this ranking and the selection criterion categories is presented by figure 5.3. Selecting a superlative option again also automatically includes the lower degree option(s), as these are still of interest to the users. For example, the technological complexity of porous pavement is considered relatively low but higher than the complexity of wetting surfaces. Hence, porous pavement has been divided into group “B”, which scores a 7 (moderate feasibility) in case adaptation measures with relatively low technological complexity are preferred, a 10 (high feasibility) for medium complexity, and a 10 (high feasibility) for measures up to a relatively high level of technological complexity.

		Feasibility ranking			
		0	**4**	**7**	**10**
Selection category	**Low**	D - E	C	B	A
	Medium	E	D	C	A - B
	High	-	E	D	A - C

Figure 5.3: Overview of the feasibility ranking for the preferred technological complexity selection criterion

5.6. Presence of solid waste

For the selection criterion of solid waste, the adaptation measures have been ranked for each of the three selection categories. The different solid waste categories have been compared for every measure, resulting in a feasibility rank for every measure and different selection criterion category as defined by chapter 4. Appendix A.6 presents a list of every adaptation measure and its corresponding feasibility ranking for each selection category, which has been mainly based on expert-judgement. For example, a bioswale is hardly influenced by low amounts of solid waste, but decreases in efficiency with increasing amounts of solid waste, because the infiltration, evaporation and discharge capacity of the measure decrease accordingly. Hence, a bioswale has been assigned a feasibility score of 10 (high feasibility) in case the presence of solid waste in the urban environment is low, a score of 7 (moderate feasibility) for a medium amount of solid waste, and a score of 4 (low feasibility) in case the presence of solid waste in the urban environment is high.

6. Implementation in the AST

The Adaptation Support Tool has been adjusted to implement the scores of the measures following from the classification of the adaptation measures and the feasibility ranking. Because of the implementation, the visual presentation of the tool has also been altered.

6.1. Calculations

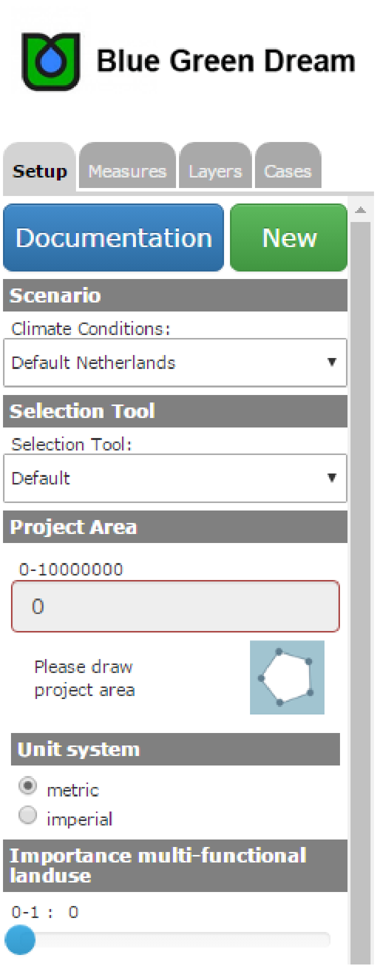
During the urban planning process, planners are given the option to set information about several characteristics of the project within the Adaptation Support Tool. As the current number of characteristics in the tool is limited, this has been expanded by the additional selection criteria presented in the previous chapters. Based on the selected characteristics by the users, different adaptation measures in the tool are selected and ranked accordingly. The tool only assigns scores based on the feasibility ranking to the measures for the selection criteria categories selected by these users. For example, if the climatic conditions are set to “Equatorial”, the tool only assigns different scores to the measures for this specific category, the scores of the other climatic conditions categories are set to zero. In addition to the aforementioned selection categories applicable to several selection criteria, the “no preference” option was introduced, allowing the users to refrain from selecting a preferred selection category. Consequently, no feasibility scores are applied to the selection criteria for which this option is selected.

Based on the chosen selection categories and the corresponding scores, the maximum score per selection criterion is selected for each measure. The total additional selection criteria score per measure is then calculated as the sum of the maximum values for every different selection criterion. Additionally, some adaptation measures are not applicable under certain conditions and therefore have not been selected as feasible measures in case these circumstances are present. Hence, measures that are assigned a score of zero for the selection category that is selected by the users, have been classified as not feasible and are therefore assigned a total additional selection criteria score of zero.

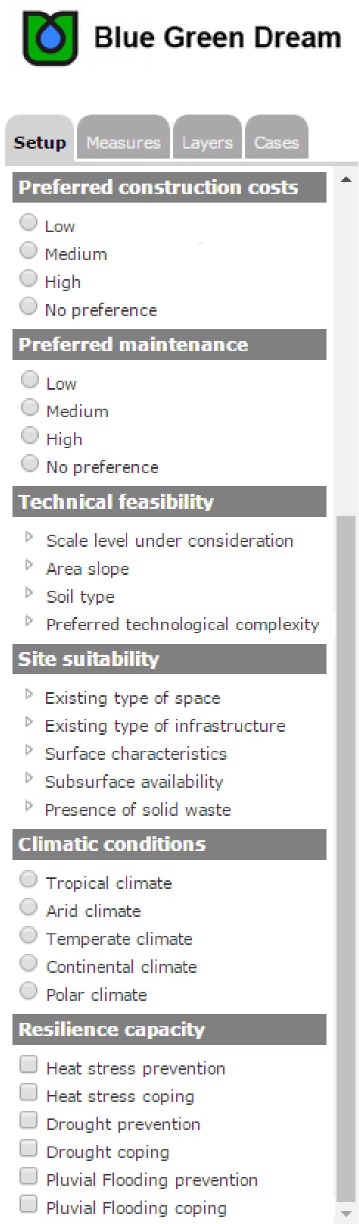
The total additional selection criteria score per measure is then combined with the total site suitability score and the total technical feasibility score, which are both already implemented in the tool. A combination of these scores results in an overall climate adaptation score in which the site suitability, the technical feasibility and the additional selection criteria are taken into account equally. Consequently, these scores are used to rank the different adaptation measures.

6.2. Visualization

The additional selection criteria have yet to be implemented in the Adaptation Support Tool, but a possible visualization of this implementation has been given nonetheless. The criteria will be implemented as additional information about the characteristics of the project area. Hence, the current left input panel (figure 2.3.a) has been adjusted to contain both the original as well as the additional project characteristics. As the amount of information an individual can process at any given time is limited, and presenting exceedingly more information could lead to an overload of information, the maximum amount of project characteristics that is immediately presented is limited to roughly six groups. Thus, the criteria presented in the left panel of the AST have been regrouped and rearranged to improve the visual presentation of the tool and the decision-making process (figure 6.1). The newly introduced technical feasibility group consists of both the original as well as the additional criteria focused on technical feasibility (figure 6.2.a), whereas the site suitability group includes the criteria aimed at site suitability (figure 6.2.b).

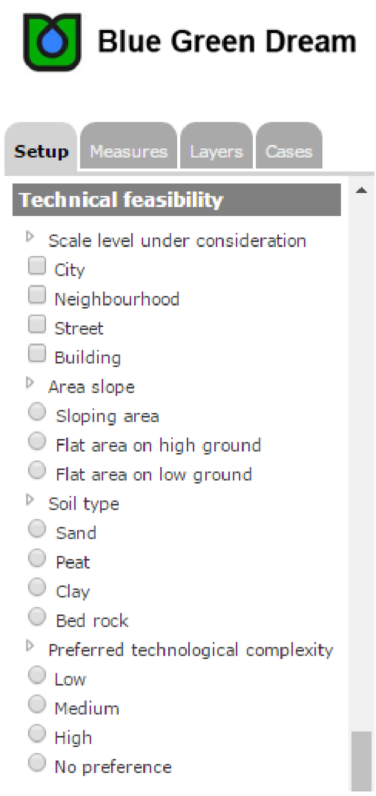


(a) *Information about the project area characteristics*

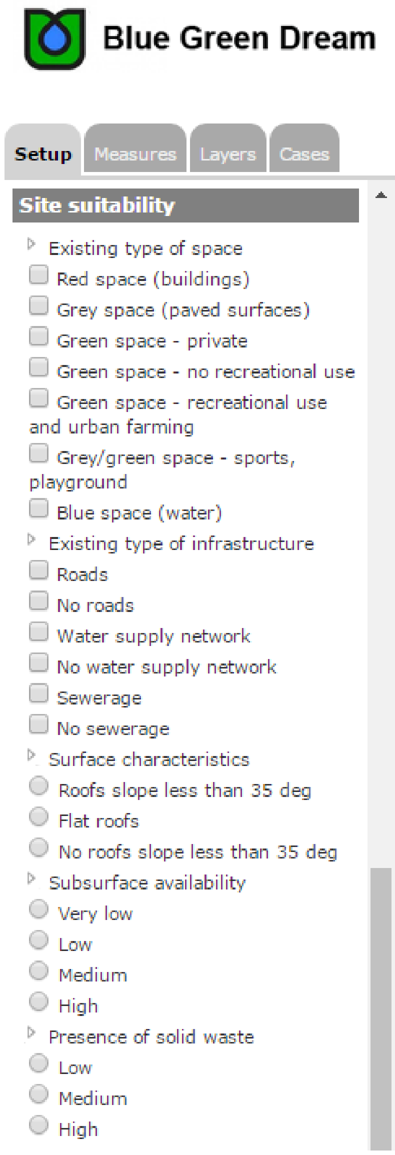


(b) *Information about the project area characteristics (resumed)*

Figure 6.1: The visual presentation of the adjusted left panel of the Adaptation Support Tool



(a) Information about the technical feasibility (detailed)



(b) Information about the site suitability (detailed)

Figure 6.2: Detailed view of the adjusted left panel of the Adaptation Support Tool

7. Evaluation

The performance of the additional selection criteria for the Adaptation Support Tool has been evaluated with two virtual case studies of cities located in developing countries subject to different climatic conditions. In both studies the tool has been used to compose two lists of measures which are most feasible at these locations, depending on the use of the additional criteria. The first study has evaluated the performance of the tool in the city of Maputo in Mozambique, and the second study was conducted for the city of Luanda in Angola.

7.1. Maputo

Maputo is the capital city of Mozambique and with roughly 1.8 million inhabitants it is also the most densely populated area in the country. Mozambique is extremely vulnerable to the effects of climate change, in particular to floods and droughts. More specifically, in Maputo the likely consequences of climate change will consist of temperature increases, sea level rise, and extreme precipitation events. Consequently, the urban planning process in the city requires the participation of multiple institutions and stakeholders, with climate change at the center of this process. [47] As the Adaptation Support Tool is developed to "support during the conceptual planning processes of stakeholders in their efforts to make the urban area more resilient to climate change" [8], it could prove extremely helpful during the urban planning process of the city.

To evaluate the performance of the Adaptation Support Tool, two lists of adaptation measures have been created. The first list has been based on the current tool in which the additional selection criteria were excluded, whereas the other list did include these criteria. The tool requires the input of multiple characteristics of the project area to create a list of feasible adaptation measures. Due to the general nature of this study, the scale level under consideration was set to "city" and "neighborhood", and the multi-functionality was turned off. Moreover, the city of Maputo can best be characterized as a flat area on low ground, built upon a relatively sandy soil. [48] According to aerial images, the vast majority of the city consists of red space (buildings) with roofs slopes of less than 35 degrees. Other existing types of space include grey space (paved surfaces, mostly roads) and green space (no recreational use). Almost three quarters of the citizens live in areas which lack common infrastructure such as water supply systems, sewerage and electricity. Consequently, it was assumed that the subsurface availability is rather high. Moreover, solid waste is abundantly present in the city, potentially blocking drainage and increasing runoff. [47] Because the financial and technological capacity of developing countries is often limited [18], it was assumed that the adaptation measures would not exceed "low" preferred construction costs and technological complexity. Moreover, as maintenance is often seen as an unimportant activity and is not given a high priority, the preferred maintenance requirement has been set to "low". According to the Köppen climate classification system, the city of Maputo features an equatorial climate with abundant rainfall during summer and only little precipitation during winter. Lastly, the resilience capacity has been mainly focused on droughts and flooding, as these are the most likely effects of climate change in Maputo. [47]

Based on the characteristics excluding the additional selection criteria, the most feasible adaptation measures included helophyte filters (wet areas with helophytes that purify water), rainwater retention ponds (wet areas that store storm water runoff), infiltration fields (green fields that store storm water runoff), seasonal storage (additional storage of storm water runoff in reservoirs), specific seasonal storage facilities (dams or water retention lakes that store storm water runoff), bank infiltration, and water squares (paved areas that store storm water runoff). However, water squares are not specifically aimed at droughts, and helophyte filters are extremely vulnerable to the presence of solid waste. Therefore, these measures were considered less feasible in this urban environment. Additionally, several other measures were characterized by rather high construction costs, maintenance or technological complexity, which did result in a different set of feasible measures in case the additional selection criteria were included in the selection procedure. The adjusted list of most feasible adaptation measures still included rainwater retention ponds, seasonal storage and specific seasonal storage facilities, but also consisted of bank infiltration (water filtration and purification through river banks), increasing the surface area of surface water bodies, and green shores and riverbanks. Hence, by considering the local circumstances in developing countries, a list of adaptation measures with a potentially higher applicability in such countries has been created.

7.2. Luanda

Luanda is the capital city of Angola, also being the country's largest city and most populated and important city. Similar to Maputo, Luanda is extremely vulnerable to the effects of climate change, albeit due to an arid climate. Hence, the Adaptation Support Tool could also prove a valuable tool in the urban planning process for the city of Luanda.

As the general nature of this study is similar for both Maputo and Luanda, the scale level under consideration was again set to "city" and "neighborhood", and the multi-functionality was turned off. Comparable to the city of Maputo, the city of Luanda can be characterized as a flat area on low, sandy ground, consisting mainly of either red space (buildings) with roofs slopes of less than 35 degrees, grey space (paved surfaces, roads), or green space (no recreational use). Although the city is classified as one of the fifteen richest cities in Africa [49], it does lack common infrastructure such as water supply systems and sewerage [50, 51]. In this case, it was further assumed that "medium" subsurface availability is not exceeded. Moreover, it was estimated that the adaptation measures would not exceed "medium" preferred construction costs, maintenance, and technological complexity. According to several images, solid waste is present in the city but to a lesser extent than in Maputo, resulting in a "medium" presence of solid waste. According to the Köppen climate classification system, the city of Maputo features an arid climate with high temperatures and a small amount of precipitation. Lastly, the resilience capacity has been mainly focused on droughts and heat stress, as these are the most likely effects of climate change in Luanda.

Based on the city characteristics excluding the additional selection criteria, the most feasible adaptation measures were somewhat similar to the measures selected for Maputo. The list again included helophyte filters, seasonal storage and specific seasonal storage facilities, but did also consist of urban agriculture and disconnecting paved surfaces from the sewer system. The difference in measures between the two cities could be mainly contributed to the difference in resilience capacity and the subsurface availability. However, taking into account the additional selection criteria, several measures became less feasible. Helophytes cannot survive in extremely dry climates, disconnecting paved surfaces from the sewer system does not apply in areas lacking sewerage, and urban agriculture is considered less feasible in arid conditions due to the low amounts of precipitation. Consequently, the list of adjusted adaptation measures consisted of increasing the area of surface water bodies, seasonal storage, cool paving and building materials, smart-drains, specific seasonal storage facilities, and bank infiltration. Several of these measures are specifically aimed at drought and heat stress, illustrating the importance of the climatic conditions in selecting feasible adaptation measures.

8. Conclusion & Discussion

The research question and sub-questions as stated in the first chapter of this thesis have been answered, based on the results of the previous chapters. Multiple conclusions have been drawn from the results and a discussion of the results and the thesis has been presented as well.

8.1. Conclusion

This thesis has shown that the adjusted Adaptation Support Tool can take into account additional selection criteria to improve the selection of adaptation measures based on different circumstances in developing countries and different climatic conditions during the decision-making process in climate adaptation of the urban environment. An extensive literature review has shown that the circumstances in developing countries are very different from the circumstances in a more developed environment, and that climatic conditions have a large spatial variability over the globe. The findings of this review have resulted in a set of six additional selection criteria specifically aimed at the feasibility of the adaptation measures under the different circumstances and climatic conditions. These selection criteria include the preferred construction costs and maintenance of the adaptation measures, the existing infrastructure and the presence of solid waste in the urban environment, the preferred technological complexity of the adaptation measures, and the different climatic conditions on the earth.

These additional selection criteria have been applied to the grey, blue and green adaptation measures by dividing each criterion into different categories that characterize the different criteria. These categories have been combined with a feasibility ranking that assigns a score based on the level of feasibility of a measure, which is similar to the already existing feasibility ranking of the tool. The scores of the feasibility ranking have been applied to each of the selection categories to generate a classification for all the adaptation measures for every different additional selection criterion. This classification has been implemented in the Adaptation Support Tool by adjusting the current calculations to incorporate the scores of the measures for the additional selection criteria. Within the adjustments these scores have been combined with the site suitability and the technical feasibility scores to provide an overall climate adaptation score per measure, which is used to rank the different adaptation measures. Consequently, the visual presentation of the Adaptation Support Tool has also been adjusted to incorporate the additional selection criteria. These criteria have been implemented as additional information about the characteristics of the project area by adjusting the input panel of the tool. The total set of selection criteria in this panel has been further rearranged to improve the visual presentation of the tool.

Two broad case studies have shown that the inclusion of the additional selection criteria could generate a list of more feasible adaptation measures in developing countries. Moreover, the same studies have shown that the inclusion of an additional selection criterion specifically aimed at climatic conditions results in a list of measures with a higher feasibility for different climate types. Consequently, the support offered by the Adaptation Support Tool during the conceptual urban planning process to make urban areas more climate resilient could be improved with the inclusion of the additional selection criteria.

8.2. Discussion

Although this thesis has shown that the inclusion of additional selection criteria could improve the selection procedure of adaptation measures and improve the decision-making process in climate adaptation of the urban environment, several actions could be taken to further improve the tool.

The division of different selection categories and the classification of the adaptation measures based on these categories and the scores from the feasibility ranking has mostly been the result of a combination of literature surveys and expert-judgement. As this judgement was only carried out by the author of the thesis, the classification of the measures could be further improved by taking into account the judgement of other stakeholders and experts specialized in the application of adaptation measures in the urban environment. This would result in a more balanced view on the feasibility scores of the measures under different circumstances as presented by the additional selection criteria and thus improve the ranking of these measures. However, the inability to empirically test the assigned scores to the measures limits the classification of the measures. Research on the influence of project area characteristics on the effectiveness of the measures is extremely rare, especially in case of multiple climate hazards. [52] Moreover, the performance of these measures also highly depends on factors such as the current state of the measure, its design parameters, its age, and recently performed maintenance. [36]

Additionally, the evaluation of the tool with the inclusion of the additional selection criteria has been done based on a virtual representation of two different project areas in developing countries. Due to the general nature of this evaluation, the information about the local circumstances of the project areas was limited, which only allowed for an impression of the effectiveness of the tool. Hence, an extensive evaluation could improve the performance of the tool as a more extensive evaluation would allow for a more precise study of the effectiveness of the additional selection criteria. Preferably, this case study would be carried out on-site, with the inclusion of different stakeholders and experts having local knowledge about the project area. Besides an improved assessment of the tool, an extensive evaluation could also provide new insights in the choice of additional selection criteria and potentially add other additional criteria to the list.

Although this thesis is specifically aimed at the inclusion of additional selection criteria to improve the selection of adaptation measures based on different circumstances in developing countries and different climatic conditions, the use of these additional criteria is not limited to developing countries. Even though the circumstances in developing and developed countries in general show large differences, the selection criteria also play an important role in the selection procedure of adaptation measures in more developed countries. Therefore, the additional selection criteria could be evaluated and used both in developing as well as in developed countries.

9. Recommendations

Several recommendations can be given that could further improve the general performance of the Adaptation Support Tool and could be addressed in future research. This thesis has shown that the local circumstances in developing countries can be different from those in developed countries. Hence, six additional selection criteria have been included in the tool to improve the selection of feasible adaptation measures. However, the selection of these measures could be further improved by extending the list of possible adaptation measures. The effectiveness of some of the measures relies on the presence of for instance infrastructure such as sewerage, which is usually present in developed countries but often lacks in developing countries. The introduction of new adaptation measures such as the construction of a sewerage system or a water supply system could therefore result in valuable additional measures to be included in the tool.

Secondly, whereas present research into climate adaptation commonly approaches the adaptation from a single climate effect or hazard such as droughts, the Adaptation Support Tool approaches climate adaptation in the urban environment by integrating both heat stress, droughts, and pluvial flooding. However, this approach is not limited to these three different climate hazards but could include more climate change effect such as fluvial, coastal and groundwater flooding.

This thesis has also shown the importance of construction costs, maintenance and financial capacity of (developing) countries. Although this information is implemented both as input and output in the tool, it can still be enhanced by including additional financial information. Currently, the costs are presented in euros per m^2, whereas multiple measures also include a certain depth. Especially the measures aimed at flooding usually take into account a storage depth, which changes the total costs of these measures with changing depths. Therefore, it could be useful to include the costs in euros per m^3 in the detail tab of the tool as well. However, special care should be taken with the comparison between different adaptation measures, especially with measures of which the costs do not rely on storage depth.

Fourthly, although the impact of climate change and adaptation measures on the urban environment is generally acknowledged, the precise level of influence is difficult to determine. Changes in climatic conditions could affect the effectiveness of adaptation measures in the future. Additionally, temporal variations such as daily and weekly differences affect the performance of these measures and their ability to store storm water runoff and supply water during shortages. The water storage capacity of a water square for instance, highly depends on the temporal distribution of precipitation events and the time in-between these events, as the maximum storage capacity is only available when the precipitation from the previous event has been drained. Hence, understanding and modelling the effects of temporal variations on the effectiveness of adaptation measures could prove extremely important in adapting the urban environment to climate change and could serve as a useful addition to the tool.

Moreover, the Adaptation Support Tool does not consider the relations between the measures and the surrounding area other than the defined project characteristics. In addition to understanding the effect of the temporal variations on the performance of the measures, including hydrological characteristics such as the distance to the nearest stream, and catchment and drainage characteristics and areas, could drastically improve the performance of the tool. Additionally, the relation between the size and type of different measures and the spatial effects on the environment are not present in the tool. Although the tool does provide information about the effects of the measures, these effects are not spatially distributed over the area, but rather presented as an overall effect for the entire project area. Hence, implementing the spatial effects of the measures could provide an additional insight into the effectiveness and the selection of these measures.

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Appendix A

Appendix A.1

Adaptation measure in AST	Climatic conditions										
	Equatorial	Arid	Temperate	Continental	Polar	Explanation (resilience capacity)					
						Heat stress Threshold	Heat stress Coping	Drought Threshold	Drought Coping	Pluvial flooding Threshold	Pluvial flooding Coping
Adding grass/herbs in streetscape	10	0	10	7	0	1	1	0	0	1	0
Adding shrubbery in streetscape	10	0	10	7	0	1	1	0	0	1	0
Adding trees in streetscape	10	0	10	7	0	1	1	0	0	1	0
Artificial urban wetland	10	0	10	10	0	1	1	0	1	1	1
Bank infiltration	7	7	10	10	7	0	0	1	0	1	0
Bioswales	10	0	10	10	0	1	1	1	0	1	1
Bioswales / Infiltrating filter swales on sandy soil	10	0	10	10	0	1	1	1	0	1	0
Building without a crawlspace	7	4	10	7	7	0	0	0	0	0	1
Cool paving and building materials	7	7	10	4	4	1	1	0	0	0	0
Cooling with water elements: fountains	7	7	10	4	0	0	1	0	0	0	0
Cooling with water elements: ponds	7	7	10	4	0	1	1	0	0	0	0
Decentral separator for road runoff treatment	10	10	10	10	10	0	0	0	0	0	0
Deep groundwater infiltration	4	7	10	7	4	0	0	1	0	0	0
Disconnecting paved surfaces from sewer system	7	7	10	7	4	0	0	1	1	0	0
Ditch or infiltration-strip	7	0	10	10	0	0	0	1	0	1	1
Extensive green roof	10	0	10	7	0	1	1	0	0	1	0

Extra intensive green roof	10	0	10	7	0		1	1	0	0	1	0
Floating puri-plants (floatlands)	10	0	10	10	0		0	0	0	0	0	0
Green facade	7	0	10	4	0		0	1	0	0	0	0
Green roofs with drainage delay	10	0	10	7	0		1	1	0	0	1	0
Green shores and riverbanks	10	0	10	10	0		1	1	1	0	1	1
Green ventilation grids	10	0	10	7	0		1	1	0	0	1	0
Gutter	7	4	10	7	7		0	0	0	0	1	0
Helophyte filter	10	0	10	10	0		1	1	1	1	1	1
Improve soil infiltration capacity	7	7	10	10	7		0	0	1	0	1	0
Inclination of roads	7	4	10	7	10		0	0	0	0	1	1
Increase area of surface water	10	10	10	10	10		1	1	0	1	1	1
Infiltration and transport-sewer	7	7	10	10	7		0	0	1	0	1	0
Infiltration boxes	7	7	10	10	7		0	0	1	0	1	0
Infiltration field	10	0	10	10	0		1	1	1	0	1	1
Infiltration shafts	7	7	10	10	10		0	0	1	0	1	1
Infiltration trench	7	7	10	10	7		0	0	1	0	1	0
Intensive green roof	10	0	10	7	0		1	1	0	0	1	0
Lower streets to store water	7	4	10	7	10		0	0	0	0	1	1
Park or urban forest	10	0	10	7	0		1	1	0	0	1	1
Porous pavement	10	10	10	10	7		0	1	1	0	1	0
Private green garden	10	0	10	7	0		1	1	0	0	1	1
Pumping station (increased capacity)	7	4	10	7	10		0	0	0	0	1	1
Rainwater retention pond	10	0	10	10	0		1	1	0	1	1	1
Rainwater storage below buildings	7	7	10	10	7		0	0	0	1	1	0
Rainwater tank	7	7	10	10	7		0	0	0	1	1	0
Raised curbs/ hollow roads	7	4	10	7	10		0	0	0	0	1	1
Reconstruct combined sewer to separated sewer	7	4	10	7	7		0	0	0	0	1	0
Reconstructing (wooden) foundations	4	7	10	7	4		0	0	0	1	0	0
Replacing leaking/draining sewers	7	4	10	7	7		0	0	0	0	1	0

Retention soil filter	7	7	10	10	7		0	0	1	0	1	0
Seasonal storage (extra storage height of surface water)	7	7	10	10	7		0	0	1	1	1	0
Sewer system (increased capacity)	7	4	10	7	7		0	0	0	0	1	0
Shallow infiltration measures, boxes	7	7	10	10	7		0	0	1	0	1	0
Smart irrigation measures	4	7	10	7	0		0	0	1	1	0	0
Smart-drain (groundwater)	7	7	10	10	7		0	0	1	1	1	0
Specific seasonal storage facility	7	7	10	10	7		0	0	1	1	1	0
Storage/settling tank and storage basins	7	7	10	10	7		0	0	0	1	1	0
Surface drains	7	4	10	7	7		0	0	0	0	1	0
Swales	7	0	10	10	0		0	0	1	0	1	1
Systems for rainwater harvesting	4	7	10	7	4		0	0	1	1	0	0
Tree pit bioretention	7	0	10	7	0		0	0	0	0	1	0
Urban agriculture	10	0	10	7	0		1	1	0	0	1	0
Use of groundwater (aquifer storage and recovery)	4	7	10	7	4		0	0	1	1	0	0
Use of treated wastewater	4	7	10	7	4		0	0	1	1	0	0
Water circulation systems	4	7	10	7	4		0	0	1	1	0	0
Water inlet systems	4	7	10	7	4		0	0	0	1	0	0
Water roof	7	7	10	4	4		1	1	0	0	0	0
Water squares	7	4	10	7	10		0	0	0	0	1	1
Wet proofing (water resistant construction)	7	4	10	7	10		0	0	0	0	1	1
Wetting surfaces (of gardens, roofs, roads)	7	7	10	4	4		1	1	0	0	0	0

Figure A.1: List of the adaptation measures in the AST and its feasibility ranking for the climatic conditions selection criterion

Appendix A.2

Adaptation measure in AST	Existing infrastructure							
	Roads	No roads	Water supply system	No water supply system	Sewerage	No sewerage		Explanation
Adding grass/herbs in streetscape	10	10	10	10	10	10		
Adding shrubbery in streetscape	10	10	10	10	10	10		
Adding trees in streetscape	10	10	10	10	10	10		
Artificial urban wetland	10	10	10	10	10	10		
Bank infiltration	10	10	10	7	10	10		Water supply network: Transport water from extraction wells to another system.
Bioswales	10	10	10	10	10	10		
Bioswales / Infiltrating filter swales on sandy soil	10	10	10	10	10	10		
Building without a crawlspace	10	10	10	10	10	10		
Cool paving and building materials	10	10	10	10	10	10		
Cooling with water elements: fountains	10	10	10	7	10	7		Water supply network: Supply water in case of droughts. Sewerage: Discharge water in case of large precipitation events.
Cooling with water elements: ponds	10	10	10	7	10	7		Water supply network: Supply water in case of droughts. Sewerage: Discharge water in case of large precipitation events.
Decentral separator for road runoff treatment	10	0	10	10	10	7		Sewerage: Redistribute water after treatment.
Deep groundwater infiltration	10	10	10	10	10	10		
Disconnecting paved surfaces from sewer system	10	10	10	10	10	0		Sewerage: Strictly adapt sewer system.
Ditch or infiltration-strip	10	10	10	10	10	10		
Extensive green roof	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Extra intensive green roof	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Floating puri-plants (floatlands)	10	10	10	10	10	10		

Green facade	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Green roofs with drainage delay	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Green shores and riverbanks	10	10	10	10	10	10		
Green ventilation grids	10	10	10	10	10	10		
Gutter	10	4	10	10	10	4		Road: Frequently transport water alongside a road. Sewerage: Discharge water to a different system (sewer).
Helophyte filter	10	10	10	10	10	10		
Improve soil infiltration capacity	10	10	10	10	10	10		
Inclination of roads	10	0	10	10	10	10		Road: Strictly adapt the road.
Increase area of surface water	10	10	10	10	10	10		
Infiltration and transport-sewer	10	10	10	10	10	10		
Infiltration boxes	10	10	10	10	10	10		
Infiltration field	10	10	10	10	10	10		
Infiltration shafts	10	10	10	10	10	10		
Infiltration trench	10	10	10	10	10	10		
Intensive green roof	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Lower streets to store water	10	0	10	10	10	10		Road: Strictly adapt the road.
Park or urban forest	10	10	10	10	10	10		
Porous pavement	10	4	10	10	10	10		Road: Mainly adapt the road.
Private green garden	10	10	10	7	10	10		Water supply network: Supply water for irrigation.
Pumping station (increased capacity)	10	10	10	10	10	10		
Rainwater retention pond	10	10	10	10	10	10		
Rainwater storage below buildings	10	10	10	7	10	10		Water supply network: Transport treated wastewater to fulfill a different purpose.
Rainwater tank	10	10	10	10	10	10		
Raised curbs/ hollow roads	10	0	10	10	10	10		Road: Strictly adapt the road.
Reconstruct combined sewer to separated sewer	10	10	10	10	10	0		Sewerage: Strictly adapt sewer system.
Reconstructing (wooden) foundations	10	10	10	10	10	10		
Replacing leaking/draining sewers	10	10	10	10	10	0		Sewerage: Strictly adapt sewer system.
Retention soil filter	10	10	10	10	10	10		

Seasonal storage (extra storage height of surface water)	10	10	10	10	10	10		
Sewer system (increased capacity)	10	10	10	10	10	0		Sewerage: Strictly adapt sewer system.
Shallow infiltration measures, boxes	10	10	10	10	10	10		
Smart irrigation measures	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Smart-drain (groundwater)	10	10	10	10	10	7		Sewerage: Drain water to a different system (sewer).
Specific seasonal storage facility	10	10	10	10	10	7		Sewerage: Transport water to places of demand.
Storage/settling tank and storage basins	10	10	10	10	10	7		Sewerage: Discharge water to a different system (surface water).
Surface drains	10	7	10	10	10	4		Road: Occasionally transport water alongside road. Sewerage: Discharge water to a different system (sewer).
Swales	10	10	10	10	10	10		
Systems for rainwater harvesting	10	10	10	7	10	10		Water supply network: Transport treated wastewater to fulfill a different purpose.
Tree pit bioretention	10	10	10	10	10	7		Sewerage: Discharge water to a different system (sewer).
Urban agriculture	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Use of groundwater (aquifer storage and recovery)	10	10	10	7	10	10		Water supply network: Extract water to a different system.
Use of treated wastewater	10	10	10	4	10	0		Water supply network: Transport treated wastewater to fulfill a different purpose. Sewerage: Discharge wastewater.
Water circulation systems	10	10	10	10	10	10		
Water inlet systems	10	10	10	4	10	10		Water supply network: Supply water for irrigation.
Water roof	10	10	10	10	10	10		
Water squares	10	10	10	10	10	7		Sewerage: Discharge water to a different system (sewer).
Wet proofing (water resistant construction)	10	10	10	10	10	10		
Wetting surfaces (of gardens, roofs, roads)	10	10	10	4	10	7		Water supply network: Supply water for irrigation. Sewerage: Discharge water to a different system (sewer).

Figure A.2: List of the adaptation measures in the AST and its feasibility ranking for the existing infrastructure selection criterion

Appendix A.3

Adaptation measure in AST	Low	Medium	High		Total costs (€/m²)	Explanation
		Preferred construction costs				
Adding grass/herbs in streetscape	10	10	10		1	
Adding shrubbery in streetscape	10	10	10		15	
Adding trees in streetscape	7	10	10		50	
Artificial urban wetland	4	7	10		100	
Bank infiltration	10	10	10		5	
Bioswales	4	10	10		70	
Bioswales / Infiltrating filter swales on sandy soil	4	10	10		70	
Building without a crawlspace	10	10	10		1	Minimal construction costs.
Cool paving and building materials	10	10	10		10	Limited additional construction costs. Guess
Cooling with water elements: fountains	4	7	10		100	
Cooling with water elements: ponds	7	10	10		40	
Decentral separator for road runoff treatment	0	0	4		1000	
Deep groundwater infiltration	0	0	4		50000	
Disconnecting paved surfaces from sewer system	10	10	10		5	Similar to the measure "Surface drains", but less expensive. Costs equal to half of these costs.
Ditch or infiltration-strip	10	10	10		5	
Extensive green roof	4	10	10		60	
Extra intensive green roof	0	0	7		500	
Floating puri-plants (floatlands)	10	10	10		10	
Green facade	0	0	7		600	
Green roofs with drainage delay	4	10	10		75	
Green shores and riverbanks	10	10	10		5	

Green ventilation grids	7	10	10		30	Similar to the measures "Adding green". Costs equal to the average of the costs of these measures.
Gutter	10	10	10		10	Similar to the measure "Surface drains"
Helophyte filter	4	10	10		80	
Improve soil infiltration capacity	10	10	10		20	Costs derived from the average of costs of different soil types (sands & gravel). [http://www.bouwmaat.nl/is-bin/INTERSHOP.enfinity/WFS/org-webshop-Site/nl_NL/-/EUR]
Inclination of roads	7	10	10		50	Costs derived from the costs for "Aanleg rijbaan voor personenauto's, bestaande uit betonstraatstenen, breedte 5 meter". [Mourik, "Prijslijst Grondverzet en Wegenbouw", 2015]
Increase area of surface water	4	7	10		100	
Infiltration and transport-sewer	10	10	10		15	
Infiltration boxes	0	4	7		400	
Infiltration field	0	7	10		200	
Infiltration shafts	0	0	7		500	
Infiltration trench	0	4	7		400	
Intensive green roof	4	7	10		100	
Lower streets to store water	7	10	10		50	
Park or urban forest	10	10	10		1	
Porous pavement	10	10	10		10	
Private green garden	4	10	10		60	
Pumping station (increased capacity)	0	0	4		1000	Costs derived from costs for the installment of a new pumping station. [https://www.adb.org/sites/default/files/project-document/81008/44458-012-tacr-01e.pdf]
Rainwater retention pond	10	10	10		20	
Rainwater storage below buildings	0	0	4		1000	
Rainwater tank	0	0	4		1000	
Raised curbs/ hollow roads	7	10	10		50	Costs derived from the costs for "Aanleg rijbaan voor personenauto's, bestaande uit betonstraatstenen, breedte 5 meter". [Mourik, "Prijslijst Grondverzet en Wegenbouw", 2015]
Reconstruct combined sewer to separated sewer	0	0	7		700	Costs derived from the costs for "Kosten aanleg rioolstrengen inclusief rioolputten". [RIONed, "D1100 Kostenkengetallen rioleringszorg", 2017]
Reconstructing (wooden) foundations	0	4	10		275	Costs derived from the costs of installing a foundation. [http://www.homeadvisor.com/cost/foundations/install-a-foundation/]

Replacing leaking/draining sewers	0	0	7		700	Costs derived from the costs for "Kosten aanleg rioolstrengen inclusief rioolputten". [RIONed, "D1100 Kostenkengetallen rioleringszorg", 2017]
Retention soil filter	0	4	7		400	
Seasonal storage (extra storage height of surface water)	10	10	10		15	
Sewer system (increased capacity)	0	0	7		700	Costs derived from the costs for "Kosten aanleg rioolstrengen inclusief rioolputten". [RIONed, "D1100 Kostenkengetallen rioleringszorg", 2017]
Shallow infiltration measures, boxes	0	4	7		400	
Smart irrigation measures	10	10	10		1	Costs derived from the costs of on-site smart irrigation controllers. [https://www.smgov.net/uploadedFiles/Departments/OSE/Categories/Landscape/Smart_ControllerFactSheet.pdf]
Smart-drain (groundwater)	10	10	10		10	Similar to the measure "Surface drains".
Specific seasonal storage facility	4	7	10		100	
Storage/settling tank and storage basins	0	0	4		1000	Costs derived from the costs for a storage tank. [http://www.cheresources.com/invision/blog/4/entry-274-cost-estimation-of-fixed-roof-cone-carbon-steel-storage-tanks/]
Surface drains	10	10	10		10	
Swales	4	10	10		90	
Systems for rainwater harvesting	0	0	4		1000	
Tree pit bioretention	0	4	10		270	
Urban agriculture	10	10	10		5	
Use of groundwater (aquifer storage and recovery)	10	10	10		15	Costs derived from the costs for an aquifer storage project. [http://www.edwardsaquifer.net/asr.html]
Use of treated wastewater	0	0	4		1000	Similar to the measure "Decentral separator for road runoff treatment".
Water circulation systems	0	0	7		500	Similar to the measure "Pumping station", but less expensive. Costs equal half of these costs.
Water inlet systems	7	10	10		30	Similar to the measure "Surface drains".
Water roof	7	10	10		50	
Water squares	0	7	10		200	
Wet proofing (water resistant construction)	7	10	10		50	Costs derived from the costs for sealing a basement. [http://www.homeadvisor.com/cost/basements/seal-a-basement-or-foundation/]
Wetting surfaces (of gardens, roofs, roads)	7	10	10		50	Similar to the measure "Cooling with water: fountains". Costs equal to the average of the costs of this measure and the costs for sprinkling water.

Figure A.3: List of the adaptation measures in the AST and its feasibility ranking for the preferred construction costs selection criterion. A blanc explanation indicates that the value has been obtained from the original cost table of the current Adaptation Support Tool.

Appendix A.4

Adaptation measure in AST		Preferred maintenance				
	Low	Medium	High		Annual costs (percentage of construction costs)	Explanation
Adding grass/herbs in streetscape	0	0	7		25	
Adding shrubbery in streetscape	0	4	7		20	
Adding trees in streetscape	7	7	10		5	
Artificial urban wetland	10	10	10		2,5	
Bank infiltration	7	10	10		3	
Bioswales	10	10	10		1	
Bioswales / Infiltrating filter swales on sandy soil	10	10	10		1	
Building without a crawlspace	10	10	10		1	Minimal maintenance
Cool paving and building materials	10	10	10		1	Minimal maintenance
Cooling with water elements: fountains	4	7	10		10	
Cooling with water elements: ponds	10	10	10		1	
Decentral separator for road runoff treatment	0	4	7		20	
Deep groundwater infiltration	7	7	10		5	
Disconnecting paved surfaces from sewer system	10	10	10		1	Similar to the measure "Surface drains".
Ditch or infiltration-strip	7	10	10		3	
Extensive green roof	7	7	10		5	
Extra intensive green roof	7	7	10		5	
Floating puri-plants (floatlands)	4	7	10		10	
Green facade	4	7	10		10	
Green roofs with drainage delay	4	7	10		6	
Green shores and riverbanks	4	7	10		10	

Green ventilation grids	0	4	10		15	Similar to the measures "Adding green". Costs equal to the average of the costs of these measures.
Gutter	10	10	10		1	Similar to the measure "Surface drains".
Helophyte filter	0	4	7		20	
Improve soil infiltration capacity	10	10	10		1	Similar to the measure "Bioswale".
Inclination of roads	10	10	10		2	Costs derived from the costs of maintenance of paved roads and gravel roads. [http://ccgovernment.carr.org/ccg/pubworks/Maintenance%20Information%20 Brochure.pdf]
Increase area of surface water	10	10	10		1	
Infiltration and transport-sewer	4	7	10		10	
Infiltration boxes	0	4	10		15	
Infiltration field	0	4	10		15	
Infiltration shafts	4	7	10		10	
Infiltration trench	0	4	10		15	
Intensive green roof	7	7	10		5	
Lower streets to store water	10	10	10		2	Costs derived from the costs of maintenance of paved roads and gravel roads. [http://ccgovernment.carr.org/ccg/pubworks/Maintenance%20Information%20 Brochure.pdf]
Park or urban forest	10	10	10		2	
Porous pavement	7	7	10		5	
Private green garden	10	10	10		1	
Pumping station (increased capacity)	0	4	7		20	Costs derived from the costs of pump systems. [https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/pumplcc_ 1001.pdf]
Rainwater retention pond	10	10	10		2	
Rainwater storage below buildings	7	7	10		5	
Rainwater tank	7	7	10		5	
Raised curbs/ hollow roads	10	10	10		2	Costs derived from the costs of maintenance of paved roads and gravel roads. [http://ccgovernment.carr.org/ccg/pubworks/Maintenance%20Information%20 Brochure.pdf]
Reconstruct combined sewer to separated sewer	10	10	10		1	Costs derived from annual network operation and maintenance costs. [https://www.hunterwater.com.au/Resources/Documents/Drawings_Plans_Specs/ Guideline---Water-and-Sewer-Cost-Estimating.PDF]
Reconstructing (wooden) foundations	10	10	10		1	Minimal maintenance

Replacing leaking/draining sewers	10	10	10		1	Costs derived from annual network operation and maintenance costs. [https://www.hunterwater.com.au/Resources/Documents/Drawings_Plans_Specs/Guideline---Water-and-Sewer-Cost-Estimating.PDF]
Retention soil filter	0	4	10		15	
Seasonal storage (extra storage height of surface water)	10	10	10		1	
Sewer system (increased capacity)	10	10	10		1	Costs derived from annual network operation and maintenance costs. [https://www.hunterwater.com.au/Resources/Documents/Drawings_Plans_Specs/Guideline---Water-and-Sewer-Cost-Estimating.PDF]
Shallow infiltration measures, boxes	0	4	10		15	
Smart irrigation measures	10	10	10		1	Minimal maintenance
Smart-drain (groundwater)	10	10	10		1	Similar to the measure "Surface drains".
Specific seasonal storage facility	7	7	10		5	
Storage/settling tank and storage basins	10	10	10		2	Costs derived from the costs for tank maintenance. [http://www.oreco.com/Solutions/Downloads/Industry-articles/A-vision-on-tank-maintenance-costs.aspx]
Surface drains	10	10	10		1	
Swales	10	10	10		1	
Systems for rainwater harvesting	7	7	10		5	
Tree pit bioretention	10	10	10		1	
Urban agriculture	0	0	4		100	
Use of groundwater (aquifer storage and recovery)	7	7	10		5	Similar to the measure "Deep groundwater infiltration".
Use of treated wastewater	0	4	7		20	Similar to the measure "Decentral separator for road runoff treatment".
Water circulation systems	0	4	7		20	Costs derived from the costs of pump systems. [https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/pumplcc_1001.pdf]
Water inlet systems	10	10	10		1	Similar to the measure "Surface drains".
Water roof	10	10	10		1	
Water squares	4	7	10		10	
Wet proofing (water resistant construction)	10	10	10		1	Minimal maintenance
Wetting surfaces (of gardens, roofs, roads)	7	7	10		5	Similar to the measure "Cooling with water: fountains". Costs equal to the average of the costs of this measure and the costs for sprinkling water.

Figure A.4: List of the adaptation measures in the AST and its feasibility ranking for the preferred maintenance selection criterion. A blanc explanation indicates that the value has been obtained from the original cost table of the current Adaptation Support Tool.

Appendix A.5

Adaptation measure in AST	Preferred technological complexity				
	Low	Medium	High		Explanation (complexity group)
Adding grass/herbs in streetscape	10	10	10		A
Adding shrubbery in streetscape	10	10	10		A
Adding trees in streetscape	10	10	10		A
Artificial urban wetland	0	4	7		D
Bank infiltration	10	10	10		A
Bioswales	4	7	10		C
Bioswales / Infiltrating filter swales on sandy soil	4	7	10		C
Building without a crawlspace	7	10	10		B
Cool paving and building materials	10	10	10		A
Cooling with water elements: fountains	4	7	10		C
Cooling with water elements: ponds	4	7	10		C
Decentral separator for road runoff treatment	0	0	4		E
Deep groundwater infiltration	10	10	10		A
Disconnecting paved surfaces from sewer system	7	10	10		B
Ditch or infiltration-strip	7	10	10		B
Extensive green roof	0	0	4		E
Extra intensive green roof	0	0	4		E
Floating puri-plants (floatlands)	7	10	10		B
Green facade	0	0	4		E
Green roofs with drainage delay	0	0	4		E
Green shores and riverbanks	10	10	10		A

Green ventilation grids	4	7	10		C
Gutter	7	10	10		B
Helophyte filter	7	10	10		B
Improve soil infiltration capacity	10	10	10		A
Inclination of roads	4	7	10		C
Increase area of surface water	7	10	10		B
Infiltration and transport-sewer	0	4	7		D
Infiltration boxes	4	7	10		C
Infiltration field	10	10	10		A
Infiltration shafts	4	7	10		C
Infiltration trench	7	10	10		B
Intensive green roof	0	0	4		E
Lower streets to store water	4	7	10		C
Park or urban forest	0	4	7		D
Porous pavement	7	10	10		B
Private green garden	7	10	10		B
Pumping station (increased capacity)	0	4	7		D
Rainwater retention pond	4	7	10		C
Rainwater storage below buildings	0	0	4		E
Rainwater tank	10	10	10		A
Raised curbs/ hollow roads	4	7	10		C
Reconstruct combined sewer to separated sewer	0	4	7		D
Reconstructing (wooden) foundations	0	0	4		E
Replacing leaking/draining sewers	4	7	10		C
Retention soil filter	4	7	10		C
Seasonal storage (extra storage height of surface water)	7	10	10		B
Sewer system (increased capacity)	0	4	7		D
Shallow infiltration measures, boxes	4	7	10		C
Smart irrigation measures	0	4	7		D

Smart-drain (groundwater)	0	4	7		D
Specific seasonal storage facility	7	10	10		B
Storage/settling tank and storage basins	4	7	10		C
Surface drains	7	10	10		B
Swales	4	7	10		C
Systems for rainwater harvesting	7	10	10		B
Tree pit bioretention	7	10	10		B
Urban agriculture	0	4	7		D
Use of groundwater (aquifer storage and recovery)	0	0	4		E
Use of treated wastewater	0	0	4		E
Water circulation systems	0	0	4		E
Water inlet systems	0	4	7		D
Water roof	0	0	4		E
Water squares	4	7	10		C
Wet proofing (water resistant construction)	0	0	4		E
Wetting surfaces (of gardens, roofs, roads)	10	10	10		A

Figure A.5: List of the adaptation measures in the AST and its feasibility ranking for the preferred technological complexity selection criterion

Appendix A.6

Adaptation measure in AST	Presence of solid waste				
	Low	Medium	High		Explanation
Adding grass/herbs in streetscape	10	7	4		Grass partially dies and the infiltration capacity is reduced due to large amounts of solid waste.
Adding shrubbery in streetscape	10	10	7		Plants could die due to large amounts of solid waste.
Adding trees in streetscape	10	10	10		
Artificial urban wetland	10	7	4		Plants partially die due to large amounts of solid waste.
Bank infiltration	10	7	7		Infiltration capacity and water quality are reduced due to solid waste.
Bioswales	10	7	4		Plants partially die and the infiltration capacity is reduced due to large amounts of solid waste.
Bioswales / Infiltrating filter swales on sandy soil	10	7	4		Plants partially die and the infiltration capacity is reduced due to large amounts of solid waste.
Building without a crawlspace	10	10	10		
Cool paving and building materials	10	10	10		
Cooling with water elements: fountains	10	7	7		Water quality is reduced due to solid waste.
Cooling with water elements: ponds	10	7	7		Water quality is reduced due to solid waste.
Decentral separator for road runoff treatment	10	7	4		Filters could clog due to large amounts of solid waste.
Deep groundwater infiltration	10	10	10		
Disconnecting paved surfaces from sewer system	10	7	7		Drains could clog due to solid waste.
Ditch or infiltration-strip	10	7	4		Plants partially die and ditches partially clog due to large amounts of solid waste.
Extensive green roof	10	10	10		
Extra intensive green roof	10	10	10		
Floating puri-plants (floatlands)	7	4	0		Plants die due to large amounts of solid waste.
Green facade	10	10	10		
Green roofs with drainage delay	10	10	10		
Green shores and riverbanks	10	7	7		Plants partially die and the water quality is reduced due to solid waste.

Green ventilation grids	10	10	7		Plants could die due to large amounts of solid waste.
Gutter	7	4	0		Gutters clog due to large amounts of solid waste
Helophyte filter	7	4	0		Plants die due to large amounts of solid waste.
Improve soil infiltration capacity	10	7	4		Infiltration capacity is reduced due to large amounts of solid waste.
Inclination of roads	10	10	7		Discharge capacity could be reduced due to large amounts of solid waste.
Increase area of surface water	10	7	7		Water quality is reduced due to solid waste.
Infiltration and transport-sewer	10	7	7		Infiltration capacity is reduced due to solid waste.
Infiltration boxes	10	7	7		Infiltration capacity is reduced due to solid waste.
Infiltration field	10	7	7		Grass partially dies due to solid waste.
Infiltration shafts	7	4	0		Shafts clog due to large amounts of solid waste.
Infiltration trench	10	7	7		Infiltration capacity is reduced due to solid waste.
Intensive green roof	10	10	10		
Lower streets to store water	10	10	10		
Park or urban forest	10	10	7		Plants could die due to large amounts of solid waste.
Porous pavement	7	4	0		Porous pavements clog due to large amounts of solid waste.
Private green garden	10	7	4		Plants partially die, infiltration capacity is reduced due to large amounts of solid waste.
Pumping station (increased capacity)	10	7	7		Filters could clog due to solid waste.
Rainwater retention pond	10	7	4		Plants partially die and the water quality is reduced due to large amounts of solid waste.
Rainwater storage below buildings	10	10	10		
Rainwater tank	10	10	10		
Raised curbs/ hollow roads	10	10	7		Discharge capacity could be reduced due to large amounts of solid waste.
Reconstruct combined sewer to separated sewer	10	10	10		
Reconstructing (wooden) foundations	10	10	10		
Replacing leaking/draining sewers	10	10	10		
Retention soil filter	10	7	4		Filters could clog due to large amounts of solid waste.
Seasonal storage (extra storage height of surface water)	10	7	7		Water quality is reduced due to solid waste.
Sewer system (increased capacity)	10	10	10		
Shallow infiltration measures, boxes	10	7	7		Infiltration capacity is reduced due to solid waste.

Smart irrigation measures	10	7	4		Plants partially die due to large amounts of solid waste, decreasing the functionality of irrigation measures.
Smart-drain (groundwater)	10	10	10		
Specific seasonal storage facility	10	7	7		Water quality is reduced due to solid waste.
Storage/settling tank and storage basins	10	10	10		
Surface drains	7	4	0		Drains clog due to large amounts of solid waste.
Swales	10	7	4		Plants partially die and the infiltration capacity is reduced due to large amounts of solid waste.
Systems for rainwater harvesting	10	10	10		
Tree pit bioretention	10	7	7		Infiltration capacity is reduced due to solid waste.
Urban agriculture	10	7	4		Plants partially die due to large amounts of solid waste.
Use of groundwater (aquifer storage and recovery)	10	10	10		
Use of treated wastewater	10	10	10		
Water circulation systems	10	7	7		Pump filters could clog and the water quality is reduced due to solid waste.
Water inlet systems	10	7	4		Channels could clog and the water quality is reduced due to large amounts of solid waste.
Water roof	10	10	10		
Water squares	10	7	7		Water quality is reduced due to solid waste.
Wet proofing (water resistant construction)	10	10	10		
Wetting surfaces (of gardens, roofs, roads)	10	7	7		Water quality is reduced due to solid waste.

Figure A.6: List of the adaptation measures in the AST and its feasibility ranking for the presence of solid waste selection criterion