BlueGreenStreets – Adapting Urban Streets for Climate Change

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1 ABSTRACT

Strategies for the adaptation of cities to the consequences of climate change such as dry periods, heat waves and urban flooding are needed. As urban streets account for about 25% of the area in inner-city neighbourhoods, they also have to be included. In the project BlueGreenStreets concepts are being developed to increase the resilience of cities by means of blue-green infrastructure in urban streets. The basic philosophy is to develop streets as 'multi-talents', taking into account not only the traffic function but also the requirements of urban drainage and green infrastructure. Concepts for the multidimensional redesign and retrifiting of existing streets in urban neighbourhoods are being developed, and tested in pilot projects. Two innovative solutions “the street as a drain” and “stormwater tree pits” are presented in detail.

Keywords: streets, blue-green infrastructure, cities, climate change, urban neighbourhoods

2 CLIMATE ADAPTATION OF URBAN STREETS

Urban citizens and greenspaces are suffering the consequences of climate change. There is a growing number of heavy rainfall events exceeding the design capacity of the urban drainage systems, resulting in urban flooding. The consequences of climate change also include the increased occurrence of urban heat islands and prolonged dry periods. Thus, the vitality of urban greenspaces and especially street trees is affected by the drought periods. These already existing challenges are expected to intensify in the near future as climate change progresses. Solutions for the adaptation of cities to the consequences of climate change are required. There is the need to adapt urban streets to these challenges, which account for about 25% of the area in inner-city neighbourhoods. Conflicts of use are particularly prevalent in street spaces, as there are spatial demands from many users and there is limited space. In dense cities, the street space is one of the large reserves of space for the provision of open space and the qualification of the quality of stay in the residential and living environment of the residents. Accordingly, there will be a demand in the future to develop the street space as a 'multi-talents' to create a win-win situation that promotes environmentally friendly transport, traffic calming climate adaptation and quality of life. Within the framework of the R&D project BlueGreenStreets (BGS) pilot projects and tangible solutions to multifunctional climate-adapted streetscape design are tested and the results summarised as guidelines for practitieners (BlueGreenStreets 2022). In addition in-depth research on technical design and effectiveness of blue-green elements in streetscapes is conducted.

3 MULTIDIMENSIONAL STREETS

Initial approaches for water-sensitive, multifunctional streetscape design have been discussed in various publications (Benden 2014; Klimakvarter 2013; Dörr & Schöning 2014; ReStra 2014 and Deutscher Städtetag 2015) as well as in R&D projects such as MURIEL, KURAS, SAMUWA and RISA. These publications from the field of urban water management stress the increasing importance of land use and in particular street space for the adaptation to climate change In a white paper on urban green (BMUB 2017), the strategies of multi purpose, water-sensitive and heat-adapted urban space is presented, but remain very general. Bridging the disciplines between urban water management, landscape design and traffic planning has been attempted sporadically with Benden 2014 and Eckart & Blaszczyk 2017 but is still predominantly at the conceptual level and has not yet reached the level of detail required for the practical design of streets. Solutions for water-sensitive streetscape design, adapting to heavy rainfall events and droughts, discussed in the field of urban water management have not yet been taken up in the design of streets. Also heat-sensitive street design with potentials for evaporation, cooling and shading have not yet played a role in practice. So far, there is a lack of tangible approaches on how a climate adaptive street design could function. This gap was addressed by the R&D project BlueGreenStreets which developed concepts to increase the resilience of cities by means of blue-green infrastructure in urban streets. The basic philosophy is to develop streets as 'multi-talents', taking into account not only the traffic function but also the requirements of urban drainage and green infrastructure.

In Germany, the concept of decentralised rainwater management has been established since the 1990s, which aims at surface retention, storage, evaporation, infiltration and delayed discharge of rainwater. Decentralised rainwater management uses an established repertoire of solutions such as water-permeable pavements, infiltration swales, trough infiltration, trough-rigole systems etc. The strategy of BlueGreenStreets builds on these concepts of decentralized rainwater management, but adds new perspectives:

- Overall planning of flow path: Decentralized rainwater management was based on a small-scale "parcel principle" draining single properties, which no longer meets the challenges of flood protection during heavy precipitation. The decentralised rainwater management is expanded to include an overall planning of the flow paths for heavy precipitation and urban flooding, taking into account streets, playgrounds and sports fields as well as open spaces (Kruse 2015).
- Multipurpose land use: For climate adaptation of urban streets, it is not longer sufficient to add up the different space demands of pedestriants, cyclists, parking flowing car traffic, street trees, rainwater management etc. as in many existing streets not sufficient space is available. Rather streets design are required, which combined the different functions of streets at the same space. For example, areas that primarily serve another main use such as the roadway or parking spaces can temporarely be used specifically as retention space or flow paths for a short time during heavy precipitation.
- Balancing water and micro climate: The elements of BlueGreenStreets aim to restore all dimensions of the natural water balance and micro climate. Thus, in addition to reducing runoff and favouring infiltration, also retention, evaporation as well as the harvesting and use of rainwater are considered. BlueGreenStreets are thus simultaneously the solution to both heat and flooding problems by integrating planting into stormwater management. In addition, the use of rainwater becomes more important for dealing with drought events and evaporation becomes more important to reduce local heat islands.
- Integrated planning: In BlueGreenStreets, different interests such as traffic safety, underground infrastructures, rainwater management, parking management, biodiversity, micro climate and human well-being come together. Through innovative approaches to the design and integration of these demands in urban streets, the vitality of the street green can be improved, water management and urban climate concerns be addressed and valuable ecosystem services can be preserved and improved. In order to realise the possibilities of multidimensional design of urban streets there is the need to overcome the inherent logics of subject-specific planning. The cooperation between different disciplines such as urban water management, urban planning, landscape planning and traffic planning is required.

Within the framework of the project BlueGreenStreets, concepts for the multipurpose redesign and retrofiting of existing streets in urban neighbourhoods are being developed, and tested in pilot projects. The results are compiled in a toolbox as a practice-oriented guideline (BlueGreenStreets 2022). The tried and tested solutions of decentralised rainwater management continue to be suitable for the collection, retention, infiltration and evaporation of rainwater of urban streets. This includes elements such as water-permeable pavements, infiltration swale, trough infiltration, trough-rigole systems, street trees greened central reservations, green walls and green facades (compare figure 1). However, BlueGreenStreet design also requires solutions that have so far been used less frequently in practice, such as the use of streets for the temporary drainage of heavy rainfall events or stormwater tree pits . These two innovative solutions are described in more detail below.

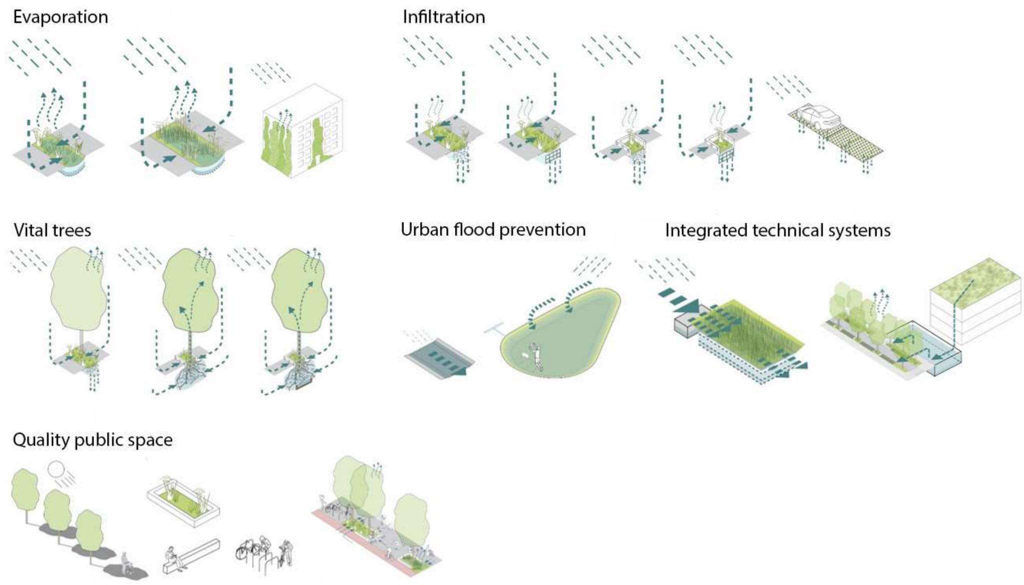

Fig. 1: Extract of the BlueGreenStreets toolbox with green infrastructur for the redesign of urban streets (BGS, bgmr Landschaftsarchitekten GmbH)

4 THE STREET AS A DRAIN

As a result of climate change, in the future heavy rainfall events will increasingly exceed the design capacity of urban drainage systems. The runoff will flow on the surface following the topography often using urban streets as the “natural” flow paths in urban settings. As result there is the danger, that urban flooding events will impact urban land uses worthy of protection. Increasing the capacity of the urban drainage infrastructure is not a realistic solution for many municipalities because of ecological and economical considerations. Up to now, mainly technical retention basins of various types have been used to manage the impact of heavy rainfall events. A new strategy to reduce flood damage in urban streets is the multidimensional use of streets for controlled temporary emergency drainage and retention of heavy rainfall (Benden 2014, Valée and Benden 2010, Günthert and Faltermaier 2016). In other words, the street is temporary used as a drain. The strategy of planned joint use of traffic areas for controlled temporary emergency drainage and retention of heavy rainfall events is being analysed in the R&D project BlueGreenStreets.

For the strategy of the street as a drain, the obligation to ensure road safety must be observed. The costs due to possible detours or accidents should be lower than the benefits of avoided damage costs from flooding. Based on an analysis of accidents during heavy rainfall events in the cities of Bretten, Karlsruhe, Solingen and Hamburg as well as video-based traffic conflict analyses a framework for the safe design of the street as a drain are identified.

- If the vehicle fording depth of passenger cars of usually 30 cm (Kramer et al. 2015) is exceeded, the cars are damaged due to the penetration of water into the engine. The traffic conflict analysis of flooded roadways shows that from water depths of more than 20 cm (plus the wave impact of the vehicles), there is a significant increase in such single-vehicle accidents (Mettmann et al. 2016). In addition the danger of slipping of pedestriants increases at water levels above 20 cm (Shu et al. 2011). Safe driving and walking on flooded roadways is therefore possible at water levels of up to 15 to 20 cm. If the water level exceeds this, the roadways must be closed.
- Depending on the water level and tyre profile, aquaplaning of cars can occur at speeds above 60 km/h (Reed et al. 1984). In order to avoid these dangers, the temporary retention of rainwater in roads with a maximum permitted speed of over 50 km/h should be avoided. The analysis of the speed driven on flooded road sections shows that most road users drive at a maximum of 30km/h (Mettmann et al. 2016). Road users thus compensate for the adverse road conditions by reducing their speed appropriately for the situation (Kyte et al. 2000). Also the accident analysis does not show more accidents on urban streets during heavy rainfall events. Hence the strategy of the street as a drain is suitable for urban streets with a maximum permitted speed of 50 km/h or even better 30 km/h.

- In order for drivers to be able to react to the flooded roadway, sufficient visibility for stopping and space for possible manoeuvres is required (Mettmann et al 2016). The road section should also not have any obstacles that are covered by water on the roadway and are not visible to road users.

Taking into account the information on road safety, concepts for the design of “streets as a drain” can be developed. In most cases, simple structural adjustments to the road profile are sufficient. High curbs, generously dimensioned gutter systems or sills are suitable for directing rainwater and keeping it away from land uses worthy of protection. The flow cross-section and retention volume of a “street as a drain” is defined by the height of the lowest trailing edge of the pavement. The retention volume of the road space can be increased by using centre channels (V-profile of the roadway) and increasing the cross slope. Swales or depressions in the road gradient should be avoided. In addition, an emergency overflow is to be provided to areas, where the flooding does not cause any damage.

The possibility of the street as a drain was investigated in BlueGreenStreets as part of a pilot project in Solingen. The goal for pilot project was to design it multifunctionally street, combining the temporary retention of rainwater on the street with the provision of additional green infrastructure in the street. The reduction of the maximum permitted speed from 50 km/h to 30 km/h allows for a reduction of the roadway width and the large intersections can be reduced. Together with a reorganisation of the parking cars, space can be provided for the design of infiltration ditches combined with trees. In addition, the profile of the roadway is redesigned in a V-shape, so that can be retained during heavy rainfall events.

5 STORMWATER TREE PITS

The vitality of the street green can be improved through innovative approaches for the design and integration of multifunctional green spaces in the streetscape. Street trees play an important role in multifunctional streetscape design. They provide a whole range of ecosystem services to the urban environment, such as reducing the urban heat island effect, filtering air pollutants, increasing urban biodiversity and having positive effects on the quality of stay. In addition, trees have important influences on urban stormwater management. They reduce stormwater runoff and soil erosion through direct retention on or wetting of leaves and branches with water (interception), drainage of water through trunk (stem runoff), and infiltration through the soil (Elliott et al. 2018). Additionally, substrates filter pollutants from stormwater before it infiltrates into groundwater (CRWSA 2009). However, urban and especially street trees often face more difficult site conditions due to various environmental factors. According to Embrén et al. (2009), the most common problems for the development of urban tree populations include lack of space (root zone), lack of oxygen, and lack of water. Drought stress, in particular, is already causing loss of vitality today. Climate change may lead to increased mortality of street trees due to an increase in extreme events (Savi et al. 2015). One possible solution is to identify tree species that can cope well with urban stresses, including heat and water shortage. Another approach is to modify tree locations and conditions to increase the vitality of urban street trees. Adapting planting sites to meet the needs of urban trees can be done primarily through the design of the planting pit and/or the composition and layering of planting substrates. Combining street trees with stormwater management measures can, in some circumstances, both increase tree vitality and reduce flooding risk by directing stormwater into tree pits (Grey et al. 2018). In terms of technical feasibility, there are several options for combining decentralized stormwater management and tree pits. Two systems have become established, so-called box or cell systems and structural soils. In Europe, the "Stockholm model", a structural soil with a coarse soil content of > 100 mm grain size, is established in several countries (f.e. Sweden, Austria, Switzerland, Denmark).

The suitability of different systems in urban locations depends on different environmental factors and objectives. The origin of the rainwater (e.g. street or roof water) plays a decisive role for the possible unproblematic use from the point of view of tree vitality and groundwater protection. The substrates or planting systems used must provide sufficient air and water storage capacity (pore distribution and volume). In addition, compaction must not occur, which is ensured by either structural soil substrates or cellular systems.

In the BGS project, different stormwater tree pit systems were planned, built and evaluated. In order to make statements on the functionality with regard to rainwater infiltration and tree vitality, monitoring of the water (level, water content and water tension) and soil air (O2, CO22) balance is carried out in the pilot projects. Long-term results demonstrating improved tree vitality in such elements or effectiveness as a stormwater management measure, especially during heavy rain events, are not currently available. In the long term, the diversity of the pilot projects in terms of substrates and technical/structural elements should help to close the gaps in knowledge regarding water and oxygen supply to tree roots. In addition, the interrelationships between the discharge of additional rainwater from traffic and/or roof areas and the vitality of the trees planted in them will be investigated by measurements. In 2020 and 2021, different types of tree pits with and without underground water storage were built in Hamburg. The structurally similar types in Hölertwiete in Hamburg-Harburg and Am Beckerkamp in Hamburg-Bergedorf are supplied with rainwater from the roof or the street (Fig. 1). To store more water for dry periods, underground water reservoirs were built and their functionality is tested.

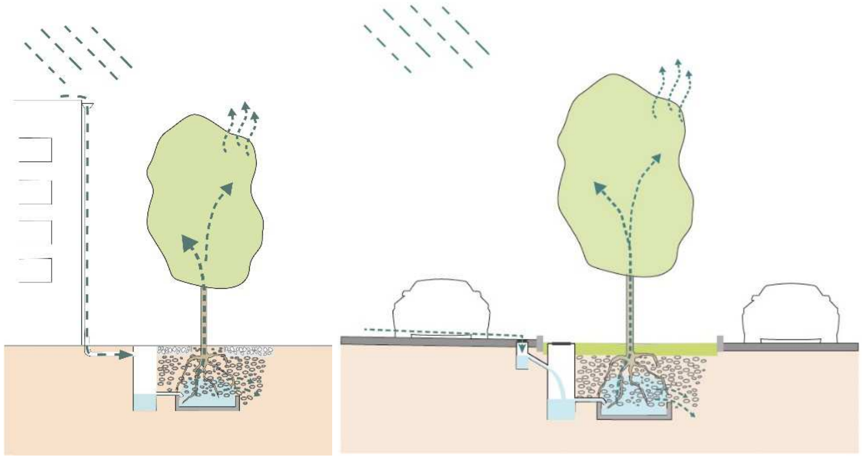

Fig. 2: Stormwater tree pits in Hamburg-Harburg (left) and Hamburg-Bergedorf (right) with underground storage elements and drainage from roofs and streets (© HCU, BGS).

The construction methods of the pilot sites differ in terms of substrates, waterproofing and drainage areas. In the Hamburg-Harburg, 2 tree pits (+ 2 reference tree pits without additional stormwater drainage) were constructed with underground bentonite waterproofing, conventional tree substrate (after FLL 2010) and an underground supply of stormwater from roof areas (Fig. 1). The tree infiltration trenches Hamburg-Bergedorf (3 + 3 reference sites) have a similar design, but are supplied from street stormwater and have a substrate mix based on the Stockholm model.

The tree pit systems showed high water management effectiveness during the first years of operation. At the site in Hamburg-Harburg, for example, < 10% of the stormwater runoff from the roof areas was discharged to the sewer system via the emergency overflow. Waterlogging, which could affect tree roots as a result of heavy rain, was effectively prevented by lateral infiltration of excess water. The stormwater tree pits and reference tree pits showed little difference in dynamics of water contents and tensions, O2 and CO2 contents at different depths in the first two years (2020 & 2021), as rooting to areas > 40 cm was probably not yet achieved. In deeper areas > 70 cm, desiccation hardly occurred and, accordingly, relatively low O2 contents prevailed in stormwater and reference tree pits. The vitality parameters stomatal conductance, leaf chlorophyll content, and leaf chlorophyll fluorescence also showed no significant differences between stormwater tree pits and references in the first two stand years. However, in the third growing season, a difference in rooting depth became apparent, possibly due to the summer drought. At the tree trench sites, several parameters indicate deeper rooting in 2022, which may indicate more effective water supply from the water storage elements. Further monitoring over as many years as possible will probably highlight the differences between stormwater tree pits and references and describe the possible effects of the increased water supply for the trees.

6 CONCLUSIONS AND MANUAL

It still seems largely unclear how trees will react in the long term to the targeted infiltration of rainwater in stormwater tree pits and how much water will be available to the trees, especially during dry periods. Technical options such as additional storage elements are currently being investigated to hold water for dry periods and make it available to the trees. Currently, there are no technical standards for such tree-rainwater systems, which makes it difficult to implement in day-to-day planning outside of pilot projects. Further categorization or standardization of built systems may be another step toward technical codest. Additional research into the effects of different systems on the urban (soil) water balance and flood and heat prevention is just as essential as gaining knowledge about the long-term effect on the vitality of different tree species.

The strategy "street as a drain" seems to be a promissing solution to reduce the risk of urban flooding caused by heavy percipitation events. The minor impairment of traffic safety through flooded streets could be offset by the reduction of damages caused by urban floods. Cost estimates indicate, that the cost for designing streets as a drain are much lower than the costs for adapting the urban drainage infrastructure to increasing rainfall events. Further questions on the operation and maintenance of streets as a drain have to be investigated pilot projects. The above mentioned requirements for the traffic safety on flooded streets can help to design and implement such pilot projects.

In the BlueGreenStreets project, a guideline "BlueGreenStreets toolbox" (BGS 2022) was created from the experience gained in pilot projects with the planning and implementation of blue-green elements in streets. It presents the current state of knowledge on such elements and is intended to contribute to the integration of water-sensitive design in planning. In the ongoing second phase of the project this guideline will be tested and evaluated in new pilot projects. Goal is the transfer of the results to practice.

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