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Flood resilient streetscape

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Abstract

The paper aims to answer the following questions: What are the trends in streetscape design? And how can streetscape become more resilient to climate change in the coming years? Although the research questions of exploratory nature also challenge theoretical claims, this is a hypothetical study, designed to foster a discussion about the visions of the future streetscape and new technology for an urban sidewalk. It covers a description and a cross-case comparison of an experimental product – the Climate Tile, implemented in Denmark in 2018, and a theoretical solution – the Sponge Pavement – a model system based on the structural soil foundation and permeable surface, evolved as an idea in 2018 in Poland. The cases are examples of innovations selected to describe a new type of water-permeable surfaces matching the urban context. Both solutions share common features: they are in that there is no need to place heavy equipment on the project site; they match the urban context of a dense city, being smooth, resistant and easy to clean. The comparison of the Climate Tile and the Sponge Pavement allowed determining the optimal application for the given solution. It also proved the trend towards the rainwater management-oriented direction of the development of the streetscape of the future. The study results could contribute to the discussion of the streetscape of the future. We would like to focus on the idea of the Sponge Pavement for further development in laboratory tests and as the pilot project.

Key words: *flood resilience, structural soil, sustainable streetscape, urban rainwater management*

INTRODUCTION

Sealing the city with non-permeable surfaces is one of the causes of urban local flash floods and consequently economic costs as the inner-city development rarely has features of flood-resilient or amphibious development. It also impacts the hydrological cycle and affects rivers flowing nearby urban agglomerations as the water transported by the sewage system after the rain is delivered to the river, quickly generating the faster water flow, the greater power of the river and the greater flood risk in the areas located downstream. Climate change affects rural [ŁABĘDZKI 2009] and urban areas [EMILSSON, ODE SANG 2017] by intensifying heavy rain events. Pavement quality contributes to rainwater ponding, which in addition to hindering walkability, damages the inner-city buildings. Therefore, there is a need to develop flexible, eco-friendly solutions for the rain-water management in dense urban areas.

Mechanistic-empirical approach of pavement design methods often involves studying the level of stress, strain, deflections and deformations due to the subgrade soil quality [PEREIRA, PAIS 2017]. New technologies for pathways [WISTUBA, WALTHER 2013; YILMAZ *et al.* 2016] take into account weather conditions, such as snow or ice accumulated on the pavement surface, and temperature induced stress. Another critical issue is flood-resilient urban infrastructure as an element in the flood hazards of walkways [LU *et al.* 2018; NIVEYDA *et al.* 2018]. NIVEYDA *et al.* [2018] point to the importance of the base layer and appro-

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priate gradation of base course materials for adequate hydraulic conductivity and/or surface layer thickness sufficient to avoid a reduction in service quality. At a local scale, creative flash flood-resilient pavement can bring relief to the whole city. If the urban sewage system after the rain is relieved by the pavement capable of water infiltration, it will also minimize the river flood risk in other sites. Considering the total area of the pedestrian movement surfaces in the city, as all the cities have pavements – even those smallest and densest, there is the potential to create an effective rainwater management system.

The article results could contribute to the discussion of the streetscape of the future. We would like to focus on the idea of the Sponge Pavement for further development in laboratory tests and the pilot project.

Streetscape has evolved dynamically during last centuries. Until the first half of the 20th century, streets served both as conduits of movement and as spaces for social gathering and interaction of neighbours, vendors, and children [GEHL 2007]. This changed with the automotive industry boom. Norton claims that cities were "physically destroyed and rebuilt to accommodate automobiles". The pedestrians had to compete for space with increasing vehicle traffic [NORTON 2011]. Visionaries hope that, as cities enter the 2020s, the question of who the streets are for will be resolved and streets will once again be a place to stroll, play, and get around safely – for everyone [Sidewalks Lab 2019]. However, researchers predict that streets will be lively only if high quality is provided [GEHL 2007].

Extreme weather patterns, including higher rainfall over shorter periods of time, noticeably affect the lives of urban residents. Heavy precipitation overloads the existing drainage systems, leading to flooding and surface erosion [KANG *et al*. 2016]. City planners will have to design climate-proof solutions and make the streets the natural process-oriented space.

The observed trends allow stating that future streets will serve not only as traffic nets for cars, bikes and people in the horizontal plane. To face climate change and water management issues, streetscapes should enable rainwater infiltration and ensure vertical movement of water. The street, initially designed as a primary corridor aligned with a stream, decked over or channelized, often into a large subsurface pipe or aqueduct, seems to experience a restoration into a blue-green line ensuring not only people but also water circulation.

The future streetscape in Växjö is an example of a kind. Located in southern Sweden, the town received the European Green Leaf Award in 2018 in recognition of its commitment to better environmental outcomes, in part owing to water and wastewater management. It is an adaptation to the forecasted climate changes by suggesting improvements to street horticulture assets and practices that can mitigate the effects of climate change. The project includes stormwater management, air pollution reduction, wind buffering, slope and soil stabilization, shade and cooling, carbon sequestration, urban heat island effect mitigation [NDEMEYE, MULHALL 2018]. The design of the streetscape in Växjö was developed in close collaboration between landscape architects, stormwater specialists and traffic planners at ÅF and the municipality. The streets ecological functions are ensured through sustainable use of stormwater together with resilient and carefully adapted plant material. In consultation with planting experts from SLU (H. Sjöman, B. Wiström), species have been selected to form an arboretum esplanade that can withstand the expected climate changes. The streets disposition has also been studied carefully from a perspective of mobility and crisis response to cope with important functions for evacuation vehicles and diversion from other street networks. First life, then space – then buildings is the motto that guided the designers [ÅF Consult 2019].

The Bagby Street, in Houston, USA, also fits in with these trends. Located in Houston, it was as the first Greenroads project in Texas reconstructed and finished in 2013. This four-lane wide street was redesigned and improved with green infrastructure such as rainwater harvesting and green basins to attenuate stormwater flows. It connects the downtown and medical district. Because of the mix-use neighbourhood around, the street also upgraded the walkability and safety for pedestrians. This project includes a critical drainage improvement project with features, such as rain gardens with turf grass and landscaping in the right-of-way, that were designed to filter harmful contaminants before any runoff could reach the Buffalo Bayou. In the summer of 2017, Hurricane Harvey put the Greenroads sustainability certification to the test and the project emerged as an excellent example of resilient and high-performing infrastructure [Greenroads Foundation 2019]. The City Government has chosen it as a good reference in renewing the city code about street construction as a good example in rainwater harvesting and pedestrian friendly. In the meantime, the green infrastructure plays an essential role in pedestrian safety and provides a natural buffer and offset to sidewalk [TAI 2019].

There is already a palette of flood resilient solutions, including ditches, bioswales, rain-gardens, street-polders or simply porous and water-permeable materials etc. The policy for the urban water system is always to catch the surface runoff and store it in reservoirs or enable its slow infiltration at the place. The area of impervious surfaces can be reduced by either limiting their dimensions or by applying semi-permeable materials on footpaths and car-parks. Popular rainwater management solutions include soft-scape option – implementing urban infiltration strips, rain gardens and technical solutions – infiltration boxes placed under porous or permeable materials used for the surfaces.

Due to a usually limited space available on the pavement, rain gardens, infiltration basins, infiltration trenches, rain gardens or urban infiltration strips [Environmental Services 2006] perform poorly in heavy rainfall. Soakaways, one of the effective Sustainable Drainage System (SUDs) practices, are recommended for dispersing surface and storm water in high density areas.

Soakaways. These are square or circular excavations either filled with rubble or lined with coarse stone or brickwork, surrounded by granular soil with adequate drainage properties. When linked together, they can help drain large areas such as highways. Modular or geocellular units can be used under roads, sports fields and parking garages [KANG 2016].

The main advantages cover the following aspects: they provide good volume reduction and peak flow attenuation and provide groundwater recharge. The water quality treatment is good, as the material keeps bigger particles. Moreover, they increase soil moisture content and help to recharge groundwater, thereby helping to mitigate problems of low river flows.

Soakaways are easy to integrate into a site, but increase the risk of saturating the structural foundations, impairing the existing drainage devices, or polluting groundwater. They may be inefficient during long wet periods [SUSDRAIN 2019a, b] and in the areas with developed tree root systems. Consequently, the design is limited to flat open landscapes.

Permeable pavements are made of porous materials, that is open pore pavers, pervious concrete (e.g. Pervia) [CEMEX 2019], woodchips, shells or gravel or stabilized mineral surface (e.g. HanseGrand or HanzaVia) [Hansegrand 2019; HanzaVia 2019] through which water can infiltrate into the soil below. The most common uses include footpaths, playgrounds, fire service roads, sidewalks, driveways, private gardens. Porous clinkers, open-joint clinkers, open paving patterns, gravel or shells are usually used in high-traffic roads and parking lots. The question is what if the base layer under the porous or permeable surfaces does not ensure water infiltration as it needs to be stable enough to keep the load.

Moreover, there are specific user demands for an urban pavement including the city context (not everywhere mineral surfaces are possible) and space left to arrange (not everywhere rain-gardens are possible). If the available space is large enough and the soil is suitable, rainwater can infiltrate directly into strips of rain gardens. The area needed for a ground infiltration plane is approximately 50% of the connected surface area [GEIGER, DREISEITL 2009]. An optimal solution for an urban pavement is thus needed, as the existing ones have their limitations and the problem of climate change is not expected to disappear.

STUDY METHODS

THE PURPOSE AND THE RESEARCH QUESTIONS

The research is based on theoretical assumptions about the situation. The project aims to answer the following questions: What are the trends in streetscape design? And how can streetscape become more resilient to climate change in the coming years? Although the research questions of exploratory nature challenge theoretical claims, this is a hypothetical study, designed to foster a discussion about the visions of the future streetscape and new technology for an urban sidewalk. The results are expected to contribute to the discussion of the streetscape of the future. This preliminary stage of the study seeks for an optimal model of an urban water-permeable surface that could be later implemented in cities.

METHODS

The paper includes a description and a cross-case comparison of an experimental product – the Climate Tile, implemented in 2018 [Tredje Natur undated], and a theoretical solution – the Sponge Pavement – an under-research model system based on the structural soil foundation and permeable surface [Jakub Heciak Architect 2019]. Both cases are purposive examples selected to describe the new type of water-permeable surface matching the urban context. They illustrate a new approach to water management in urban areas [FLYVBJERG 2006] and provide insights into the capabilities of the novel solutions for the future urban surface [VAN DEN BRINK *et al.* 2016].

RESULTS

The porous or permeable surface would not solve the problem being implemented solely in the city. To have an impact it should be a system of an adequate surface and its foundation. Two types of rainwater management systems are described in the study.

THE CLIMATE TILE – A WALK ON WATER

It is a Danish project started in 2014 by the Tredje Natur studio team. The pilot sidewalk was inaugurated in September 2018 and has already won several awards: Popular Science's 'Best of what's new', Grand Award Winner; Danish Design Award, Finalist; SDG Tech Award, Finalist. The purpose of the 50 m long pilot sidewalk in Copenhagen is to verify the performance of the Climate Tile in all seasons and to find out how it handles different weather types, loads, salting, etc. The location was chosen in close cooperation with the Municipality of Copenhagen.

The water is directed primarily to the holes that redirect it via tunnels into the planted spaces. The plants use some of the water and some will sink into the soil. Through the same holes the water from the sidewalks flows into the pipes towards the storage unit. In winter, the water with a high content of salt is transferred directly to the sewers. As a climate adapted, globally scalable solution, the Climate Tile is capable of handling 30% of the projected extra rainwater from buildings, roof and urban space, thereby reintroducing the natural water circulation in the city, limiting the pavement and infrastructure damage risk, reducing the amount of water in the existing sewer system, and preventing the costs of building or improving new storm water management facilities.

The system is extremely flexible, adjustable, and works like Lego bricks. The pilot system has been optimized on-site to adapt to some unknown underground infrastructure. The Climate Tile is fitted with vertical and horizontal pipes that allow it to respond to various needs. Plugs for the holes in the surface are used for water catchment adjustment over time and, when fitted with sensors, to collect data on water supply. The goal is to have an intelligent multi-functional solution adapted to the expected climate change effects.

Since it is still only a start-up with a pilot, it is difficult to be accurate on pricing. But the tile, when manufactured competitively, will be precast from dry mix concrete. This is an extremely fast and cheap way of production and the tile, which is only one of many components in a standard sidewalk, is expected to be competitive and an attractive investment to many customers. The tile meets all the standards requirements. After a full year of monitoring there have not been seen any tendency towards blockage of the tile holes – something which is a known problem with arbitrary permeable concrete tiles. The system is currently patent pending and negotiations with partners in Europe and North America are held. It is will be commercially available in 2020/2021.

THE SPONGE PAVEMENT – A TREE-FRIENDLY SOLUTION

This is still a theoretical model of a permeable concrete tile that allows water to infiltrate into the structural soil layer developed by the authors of the paper. The initiators of the project assume that the concrete tile with dimensions of max. 40 × 40 cm or less will constitute a flexible solution for dense urban fabric as its implementation will not need any heavy equipment. The essential element of the rainwater management system lies beneath the surface and it is the foundation. It is a structural soil layer which acts as a sponge with possible 30% water capacity considering that the soils beneath are poorly permeable. However, when there are gravels or sands beneath, the rainwater infiltrates deeper. The solution is tree-friendly as it enables tree roots to penetrate inside the structural soil and be better nourished.

Structural soils have been implemented widely to improve plant growth but not for rainwater management. The idea was developed by Jakub Heciak Architect studio and submitted in an urban competition held in November 2017 in Poland. The study area covered several streets in Milanówek – a small satellite town nearby Warsaw, planted with old historic oaks. The concept was awarded a distinction for a tree-friendly orientation (Fig. 1).

The structural soil was developed and tested in the 1990s by the Urban Horticulture Institute of Cornell University as a stone and soil mixture able to improve the habitat conditions (air-humidity) of trees in city environments [Kalter 2018; America's Premier Paver 2019]. Since then, many companies worldwide have introduced their own brands of the material based on the blended soil patented by Cornell University (CU-Structural Soil). ZinCo structural substrate [GCL 2019] is one of the examples.

The substrate consists of a mix of large size gravel (aggregates usually of limestone or granite 100–150 mm), clay and a hydrogel stabilizer [GRABOSKY, BASSUK 2016]. Its porosity is 30% to allow filling the void spaces with water during rainfall. The review of design and implementation documentation shows that the structural substrate developed in Poland and based on locally available materials is a system of two layers: the bottom layer of the substrate, laid on relaxed domestic soil, with a thickness from 40 to 70 cm depending on the type of soil is the vegetation layer; the upper layer, the aeration layer is 20 cm thick. The system is a stone and soil mixture laid as a foundation for pavements intended for pedestrian traffic, parking spaces, lawns or planting beds with vegetation. It meets the requirements of road standards in terms of load capacity and density, and the requirements for root system devel-

Fig. 1. Visualization of the structural soil general idea; source: Jakub Heciak Architekt [2019], modified

opment conditions. The aeration layer is a stone and soil mixture laid under the layers of a pavement structure, bicycle path, or parking space, from where water is drained via an aeration pit. The vegetation layer is the mixture laid under the aeration layer in which the roots of trees develop. Water is then filtered into the natural soil and collected by tree roots [SUCHOCKA 2018]. The hydrogel is added in a small amount to prevent separation during mixing and placement. The dry hydrogel is spread evenly on top of the gravel layer, then the wet clay is placed on it. The ingredients are mixed until a homogeneous mixture is obtained. The structural soil is usually not imported ready but is created on-site immediately after delivery of individual components [BARTENS *et al*. 2009].

The thickness of the structural substrate layer is often 600 mm or more. The layers are compacted with at least four passes of the surface vibrator. The soil is applied in several layers. The aggregate must be visible in the ground-filled organic layer. The structural medium is fertilized with a slow-release fertilizer having an 8-month washing time. The dose is 100 $g \cdot m^{-2}$. Fertilization takes place while laying the structural substrate, and the fertilizer is laid in layers with the substrate. To align the structural matrix, a 200 mm supporting layer made of 32–63 mm aggregates is laid on top. The material is compacted using a 400kg vibrator [EMBRÉN *et al*. 2009]. Ventilation wells allow the access of oxygen to the roots, watering and fertilizing trees, and distribution of rainwater brought to the ground.

THE CLIMATE TILE VERSUS THE SPONGE PAVEMENT

The described streetscapes from Sweden and United States illustrate the water management-orientation as a direction of the development of newly designed communication corridors. Although they represent an example of introducing the strips of greenery or rain gardens, not every city streetscape has enough space to follow this strategy. Therefore, the option for a dense urban fabric should focus on using pavement itself as a tool for rainwater management. The case study comparison covers two solutions matching this context (Tab. 1).

Table 1. Climate Tile versus Sponge Pavement

Sidewalk properties	The climate tile	The sponge pavement
Water capacity	30%	30%
Load-index	only pedestrians	mainly pedestrians, possible other options
Tree – roots friendly	no	yes
Underground city infrastructure friendly	no	yes
Flexibility	no heavy equipment needed	no heavy equipment needed

Source: own elaboration.

Both solutions share common features: they are flexible in that there is no need to place heavy equipment on the project site, contrary to the pervious concrete; they match the urban context of a dense city, contrary to harsh mineral surfaces. The difference lies in the foundation. If there is clay or other impermeable soils, the Climate Tile will probably be a better option as the rainwater is transported away from the place in a controlled way. However, where there are conditions that water could infiltrate more deeply, the Sponge Pavement is a better option. Rain will have the chance to refill the underground water deposits. The comparison of the Climate Tile and the Sponge Pavement allowed the selection of the optimal application for a given solution. It also confirms the trend for the rainwater management-oriented direction of the streetscape of the future.

DISCUSSION

This research illustrated the trends of incorporating rainwater management in the streetscape by reducing the surface runoff and enabling water infiltration. As confirmed in this paper, such trends are already visible all over the world and there are examples of newly designed streets with rain gardens (see: A future streetscape in Växjö, Sweden and The Bagby Street, Houston, USA). Researchers find rainwater management as an element of sustainable smart-streetscape of the future [MOUSSA 2017; REHAN 2013] crucial to face water shortages predicated in many countries and costs of local flash flooding [Future Cities 2019; International Water Association 2019].

However, separated rain gardens would not have such an impact as the whole systems of rainwater management and technical solutions enabling water infiltration process. Concerning the features of the Climate Tile and the Sponge Pavement, they could be a successful tool to combat flash floods (RESULTS – The climate tile versus the sponge pavement) and they could contribute to a sustainable streetscape of the future. The limitations of this study result from the fact that only theoretical considerations are presented. More extensive and thorough verification of the performance of prototype solutions requires building a pilot model of the Sponge Pavement, which is the intention of the authors of this paper.

CONCLUSIONS

The flood resilient solutions described in the article are intended to identify potential alternatives for the climate change adaptation strategies. It is important to note:

- The presented solutions are not comprehensive list of resiliency actions that may be relevant.
- There are certain circumstances in which provided solutions are likely to be appropriate.
- There should be conducted further tests focused on modelling the water flow and researching the accumulation properties of the water-permeable Sponge Pavement. The research should include: preliminary tests – computer modelling of water-permeable pavements, used material properties testing and finally water flow and retention investigations conducted in a specialized test stand.

The solutions described in the article have great importance for the disciplines of architecture and urban planning, civil engineering and transport. They concern development the solution of a real problem and have great application potential to continue research and further implementation.

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