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GREENING THE HEART OF THE CITY: AN URBAN ROOFTOP DRAINAGE SYSTEM INSIDE A GARDEN FENCE

by **ALAN PETRILLO**

A handsome willow-sheathed fence in Copenhagen conceals a secret: It is actually a sustainable urban drainage system (SUDS) that disperses rainwater collected from the roofs of nearby apartment buildings. A collaborative simulation-driven design process turned this infrastructure into an urban amenity, which protects neighborhood gardens, mitigates noise pollution, and helps prevent frequent rain from overflowing city drainage systems.

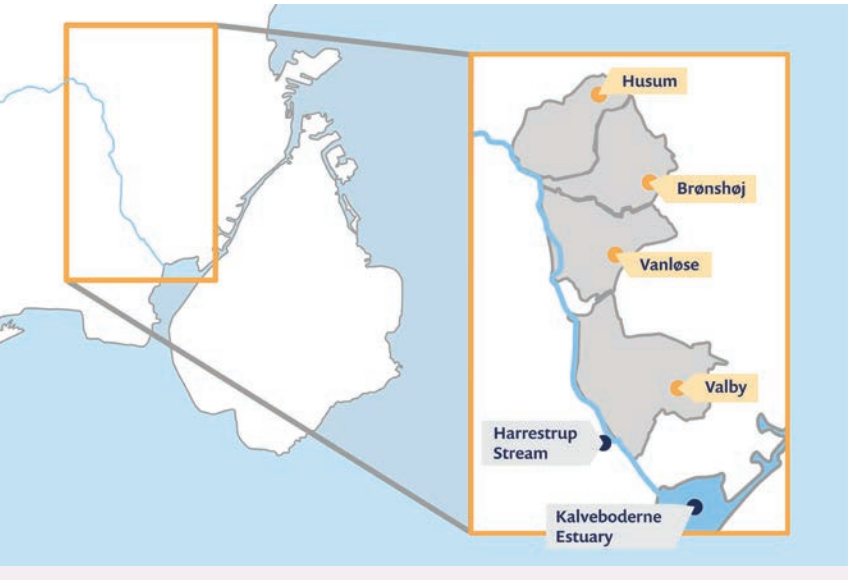

FIGURE 1 An aerial view of Denmark. The inset indicates a region with about 100,000 residents. Rainwater runoff in this zone causes approximately 200 combined sewer overflows per year into the Kalveboderne Estuary, which discharges into the harbor.

"The green parts of the city are precious," says Marina Bergen Jensen, professor of landscape architecture and planning at the University of Copenhagen. They are also frequently under stress. We ask these often-neglected parcels of land to help manage air quality, noise pollution, and drainage, even as we expect them to serve as oases of natural beauty and calm. To make the most of this essential urban space, Prof. Jensen led a project to develop a new kind of infrastructure: a wood-sheathed "green screen" that protects and enhances a densely populated Copenhagen neighborhood — and provides an ingenious system for dispersing rainwater runoff from nearby rooftops.

Much like a city itself, the urban green screen is a fascinating combination of elements that come together to serve multiple purposes. And like city life, it was created by a broad mix of people and organizations, each contributing their distinctive talents to the resulting project. A team of engineers, architects, and citizen stakeholders was guided by Prof. Jensen's vision for a more livable, sustainable city. The resulting concept could benefit any community where

people share precious living space with buildings, cars, and infrastructure.

» "A HOLISTIC HUMAN PERSPECTIVE OF CITY LIFE"

It may be surprising that Prof. Jensen's PhD training was not in architecture or urban planning. "My background is in soil science and water chemistry, and the interaction between soil, water, plants, and micro-organisms," she says. "But urban areas have become my research field, so I work with planners and landscape architects. My career is built around a holistic human perspective of city life."

In Copenhagen (Figure 1), this perspective must encompass frequent rainfall in a densely developed environment. Most urban rainwater falls on rooftops, streets, and other impermeable "hardscape" surfaces, rather than seeping into the soil. This water is typically collected by storm drains, which means that heavy rains can overwhelm sewage treatment systems and sometimes flood city streets with a mix of rain and wastewater. To better manage these risks, Prof. Jensen and her colleagues work to develop sustainable urban drainage systems (SUDS).

"It is estimated that at least 50% of all rainwater runoff in Copenhagen originates from rooftops. Most of that water drains into city sewers, but it does not have to be that way," explains Prof. Jensen. "It should be possible for us to mimic nature's own processes and let more water seep into the ground or evaporate."

» CARRYING RAINWATER FROM ONE ROOF TO ANOTHER

As part of a government-sponsored initiative, a multidisciplinary team began developing a SUDS program for a dense Copenhagen neighborhood in 2013 for a five-year period. They proposed a solution that collects rainwater from rooftop gutters and downspouts, but from there, the similarities to conventional urban drainage systems end. Rather than flowing down into the sewer, the system uses gravity to push rainwater up to the top of a freestanding wall structure (Figure 2). In other words, water gets removed from a building's roof, only to be deposited on top of a different roof. Why?

The purpose of this counterintuitive process is evaporation. Just as water in a puddle will eventually dry up, most of the water moving through this system will also evaporate (Figure 3). The urban green screen structure functions as a kind of vertical puddle that holds water above the ground, where it can be dispersed through evaporative action.

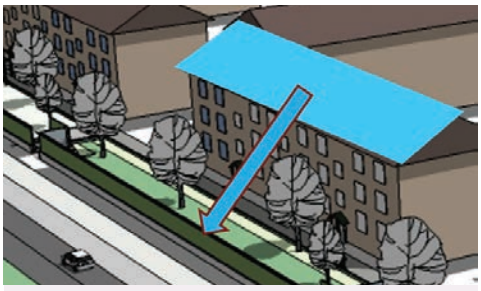

FIGURE 2 The path of rainwater as part of a SUDS proposal for a Copenhagen housing complex. Concealed pipes carry water from the buildings' rooftops to an evaporative system concealed inside a streetside noise barrier. Image courtesy Emilia Danuta Lausen and Marina Bergen Jensen.

FIGURE 3 Schematic of the urban green screen's water dispersal system. Gravity pushes rooftop runoff to the top of the screen structure, where it flows along a perforated gutter. Water then drains from the gutter into absorbent mineral wool blocks, which are exposed to evaporative airflow. Images courtesy University of Copenhagen.

After gravity pushes rainwater to the top of the structure, it flows along an open perforated gutter. Some water will evaporate from the gutter, and some will flow down into the body of the screen, where it is absorbed by blocks of fibrous "mineral wool." This rock-based material is often used as heat-retaining insulation in Nordic countries. In the urban green screen, it functions as a sponge, receiving water from the roof and then gradually releasing it into the air. If the mineral wool blocks become fully saturated by heavy rains, some water will be released from the bottom of the structure. This excess water is captured in a soil-filled chamber, where it helps irrigate vines and other decorative plants. The plants' scheme was developed to ensure lush green vegetation that supports biodiversity (insects, birds).

FIGURE 4 A Pilebyg noise barrier along a Danish highway.

"The structure is designed to disperse as much water as possible, while taking up as little space as possible," explains Kristoffer Ulbak, a civil engineer focused on water management, who helped guide

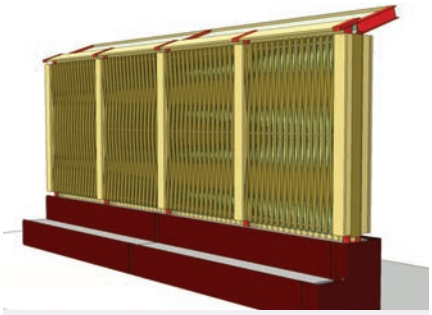

FIGURE 5 An illustration of the final design for the urban green screen. A steel footing and structural frame supports the willow-sheathed mineral wool blocks and roof/gutter assembly. Image courtesy TL-Engineering.

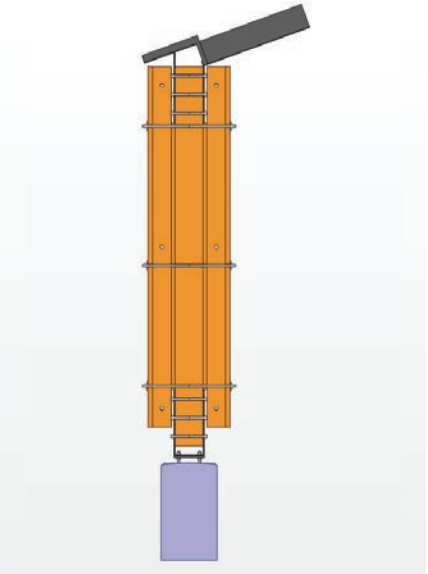

FIGURE 6 The urban green screen model geometry. Images courtesy TL-Engineering.

the urban green screen project. "We also thought it could be a solution to more than just the water problem. It serves as a noise barrier and it could potentially absorb particulate pollution from the roads," he says. Also, evaporative action can lessen the "urban heat island" effect, in which cities are often significantly warmer than surrounding countryside.

A FENCE, NOT A WALL: THE NEED FOR A NEIGHBORLY URBAN PARTITION

Along with addressing these functional needs, the design team also had to consider the "holistic human perspective," as Prof. Jensen described it. A tall, solid wall full of slowly evaporating water may bring functional benefits, but it would not be a welcome presence in people's front yards. "We had meetings with residents early in the project," explains Prof. Jensen. "Some of them feared [the screen] would make their community feel like a prison."

The residents' concerns were a reminder that a neighborhood's "furniture" must serve as architecture, not just infrastructure. This is why the urban green screen's steel frame and mineral wool blocks are mostly invisible. It looks like a wooden fence, not a metal and masonry wall. The screen is also equipped with benches for sitting and with meadow vegetation. Two windows give a look to the street, and a window at each end of the screen gives security for pedestrians so they can see what is going on around the corner when passing. Achieving this design, which meets water management goals while being both attractive and structurally sound, was a challenge for the project team.

"I am a civil engineer," says Ulbak. "I know a lot about how to evaporate water! But we had to address other problems. We had meetings where some people asked, 'Can you just put up a glass wall?' They were concerned about not being able to see the street. But the project brief was to make a wall that disperses water, and you cannot evaporate much water from glass," he explains. "These are some of the obstacles we met. Each step forward could take months of back-and-forth toward a better solution."

A "WILLOW BUILDING" TO CONCEAL A DRAINAGE SYSTEM

At this point, consulting structural engineer and simulation specialist Tim Larsen, TL-Engineering, joined the project. His skills and experience with infrastructure projects helped the team address the green screen's multiple challenges. "When I first joined the project, there were a lot of ideas on the table. They presented me with some architectural drawings of a design that would not stand if the wind was blowing," Larsen recalls. "I proposed a completely steel structure, but I was told that the community could not accept that. This is when I suggested reaching out to Pilebyg."

Pilebyg's name combines the Danish words for "willow" and "building," and they have been building innovative structures from willow trees for more than 30 years. Their process involves cultivating willows so that their trunks grow into relatively uniform curved shapes. The harvested trunks can then be "woven" around a support frame made from steel or other types of wood (Figure 4). Special treatment enables the willow sheathing to last for decades, both protecting the structure and helping it complement the landscape. "You would not call a tree ugly because it is old," says Vibe Gro, Pilebyg's co-owner and project manager for the green screen project. "We offer a façade that can age beautifully."

SIMULATION SUPPORTS THE DESIGN/BUILD PROCESS

Pilebyg noise barriers have become a familiar site along Danish highways, but the company had never before built a fence that concealed a drainage/evaporation system. To help combine multiple materials and functions into a robust and harmonious structure, Tim Larsen, who has a master's degree in civil engineering, developed simulations using the COMSOL Multiphysics® software (Figure 5).

"It was funny, because Tim was not part of the project when we started, but his work was essential to our reaching a viable solution," explains Ulbak. He likens the use of simulation to looking at instructions for building a set of toys; the project stakeholders were able to look at the simulation results and tell how all of the pieces of their project fit together.

Tim Larsen used simulation to ensure that the structure was strong enough for Copenhagen's climate (Figures 6–7). Multiphysics analysis helped verify that it could withstand wind pressure, the varying loads resulting from water flowing through its porous exterior, and water saturating its mineral wool core.

"There are a lot of materials involved in a structure like this, and small changes can have a big impact," says Larsen. "A little overhang on the top does not look like much, but when it fills with water, it can create a heavy bending moment, especially when the wind is blowing," he explains.

As the project moved closer to completion, images from the COMSOL models were shared with other stakeholders. The same schematics provided to the crews building the

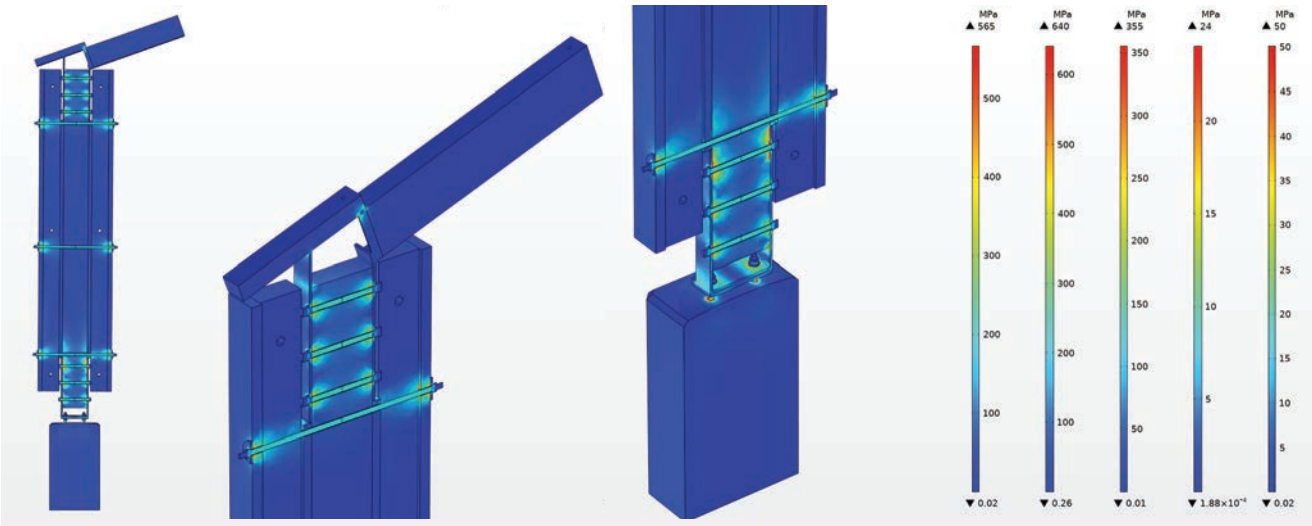

FIGURE 7 Results from the stress analyses of the urban screen. Model images courtesy TL-Engineering.

FIGURE 8 A section of the completed urban green screen in 2019 (left) and 2020. Note the vertical glass window and the emergence of native plant life between the screen and buildings.

structure also helped explain it to the organizations that provided funding. "The simulation was an analytical tool that also supported our design discussions, and now it helps us promote the concept to others," says Kristoffer Ulbak.

» PLANTING THE SEEDS FOR GROWING MORE GREEN SCREENS

After approximately 6 years of development, the urban green screen was installed in Copenhagen in 2019 (Figure 8). The completed structure addresses the priorities of everyone who contributed to its design — including those who would have preferred a barrier made of glass. A series of vertical windows provide visual breaks in the willow-clad surface, and add "eyes on the street" to help ensure neighborhood safety.

So far, the structure is succeeding at both dispersing moisture and quieting traffic noise for residents (Figure 9). "When you move from the street to the housing side of the screen, it is like going into paradise," says Prof. Jensen. Reactions from the various stakeholders have been positive, although the global COVID-19 pandemic and other factors have complicated attempts to study the installation in detail. Prof. Jensen, befitting her scholarly perspective, wants to do more research before declaring it a success.

"We believe that air quality on the residential side of the fence is better, and evaporative cooling should help reduce the 'urban heat island' effect. We need more testing to confirm this," she says. "There is also the question of perception. We want to monitor how people use the space and interview the residents who live with the structure every day."

Even as the project awaits further follow up, there is already some telling evidence of the green screen's acceptance: It does not attract graffiti. Pilebyg's Vibe Gro is not surprised. "Our structures are often in areas that get vandalized, but it seems like people act differently around trees, even if they are installed as part of a structure," she says. "We have a rainwater solution that solves a noise problem, and it is a structure that people feel comfortable living with," says Gro. "In Danish we say, 'It takes out two flies with one smash!'" ◎

FIGURE 9 An overhead view of the completed structure and a street-side view of the urban green screen.