Participative evaluation of Sustainable Urban Drainage systems with ClimateCafé Malmö

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Floris Boogaard, professor at the Hanze University of Applied Sciences Groningen, Holland, has launched tools to increase climate adaptability including ClimateScan and ClimateCafé.

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Malmö is well known within the field of urban hydrology, as the city was a pioneer in integrated water management (Stahre 2008). In 1998 the Augustenborg neighbourhood was refurbished due to its reoccurring problems with flooding and damage caused by water (Niemczynowicz 1999). The project "Ekostaden" (Eco-city) included many initiatives implementing nature-based solutions (NBS), such as swales and rain gardens for infiltrating surface (storm) water into the ground (Climate Adapt 2016) (Figure 1). International stakeholders want to know if these NBS still function satisfactorily after 20 years and what we can learn from the "Augustenborg strategy" and apply in other parts of the world. To quote the German philosopher Georg Wilhelm Friedrich Hegel, "we learn from history that we do not learn from history."

Augustenborg is an ideal location to demonstrate the sustainability of NBS, test the functionality for infiltration of surface water in swales, map the build-up of potential toxic elements (PTE), and test the water quality after 20 years operation. This evaluation is done in 2019 with the international, participatory and multidisciplinary method 'ClimateCafé and the results are presented at the international seminar Cities, rain and risk, June 2019 in Malmö (Boogaard *et al.* 2019).

ClimateCafé is a field education concept involving different fields of science and practice for capacity building in climate change adaptation. Over 20 ClimateCafés have already been carried out around the globe (Africa, Asia, Europe), where different tools and methods have been demonstrated to evaluate climate adaptation. The 25th edition of ClimateCafé took place in Malmö, Sweden, in June 2019 and focussed on the Eco-city of Augustenborg. The main research question - "Are the NBS in Augustenborg still functioning satisfactorily?"- was answered by interviews, collecting data of water quality, pollution, NBS and heat stress mapping, and measuring infiltration rates (Boogaard *et al.* 2020).

The main aim of ClimateCafé Malmö was to exchange knowledge in the field and raise awareness on climate adaptation in an urban area where NBS have been implemented. ClimateCafé Malmö took place on the 11th and 12th of June 2019, with the participation of 20 young international professionals, which included students and employed professionals (national, regional, and local governments, companies and NGOs). The workshops were guided by international experts from The Netherlands, Brazil, Norway, and Portugal. This interdisciplinary approach should encourage implementation of nature-based solutions, with the holistic knowledge of its functions, challenges, and possibilities and raise international awareness on climate adaptation. Table 1 shows the details of the participants and their thoughts about climate adaptation and ClimateCafe.

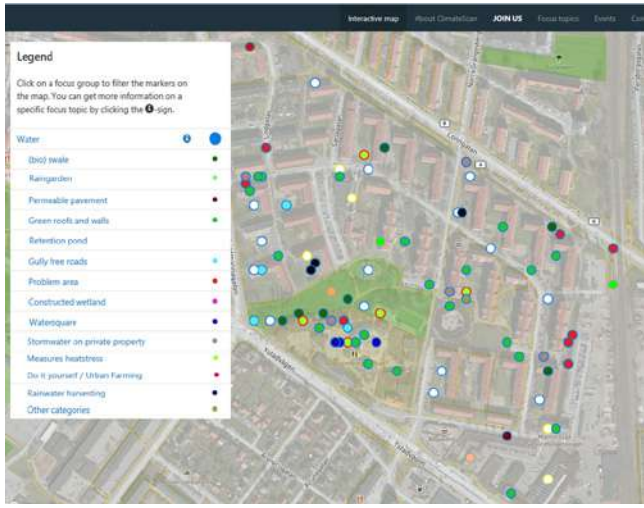


Figure 1. Map of Augustenborg, showing nature-based solutions (NBS) that have been mapped and evaluated during ClimateCafe Malmö (source: climatescan.org)

Countries	Background	Field	What are your thoughts about climate adaptation?	How did ClimateCafé improve skills about climate adaptation?
		Stormwater quality	Need to educate people	More knowledge about climate adaptation (discussions)
Sweden (7)		Civil engineering	Need more studies, more knowledge	More knowledge about climate adaptation (new techniques)
Sri Lanka (1) Indonesia (1)	PhD students (5)	Water resources engineering	Important due to climate change (e.g., disasters)	Networking (people from different backgrounds/countries)
Czech Republic (1)	Masters students (7)	Environmental engineering	It's a challenge	
Romania (2)	Bachelors students (1)	Landscape architecture	Ongoing field with a lot already happening	Spread the knowledge known to hometowns
Latvia (6)	Professionals (7)	Groundwater engineering	Important topic to spread to other stakeholders, e.g., municipalities	Experience theory on field (by measurements)
China (1) Belgium (1)		Urban drainage system	Do not have a strict opinion, need more time to verify if climate is changing	Inspiration for future studies by solutions already applied on field
		Water management	Necessity of more resilient cities	

Table 1. Participants of the Malmö ClimateCafé, background and questions asked during the event for storytelling. A total of 50% of the participants were woman (SDG 5).

Materials and general method

ClimateCafe started with a field trip at the Scandinavian Green Roof Institute and the Augustenborg Eco-city to discuss adaptive strategies implemented (Figure 2).

ClimateCafé Malmö consisted of six workshops including storytelling, climate adaptation mapping, soil quality mapping with a portable X-ray fluorescence (pXRF) instrument, water quality measurements using water drones (ROVs: remote-operated vehicles) and hydraulic efficiency evaluation by a full-scale flooding test of a swale (Figure 3).

Taking part in data collection within all workshops provides insight, creates awareness, and builds capacity within multidisciplinary fields of climate adaptation. All the measurements were conducted by the participants, supervised by experts in those particular fields, therefore assuring that beyond the gathering of data, discussions about climate adaptation and tools took place in the various workshops (Figure 3). The aim of each workshop followed by the method used are described in Table 2.

Figure 2. Above: Introduction to the green roof institute by Helen Johansson (Sweden) Below: discussions in the field with Guri Venvik (Norway) in a swale.

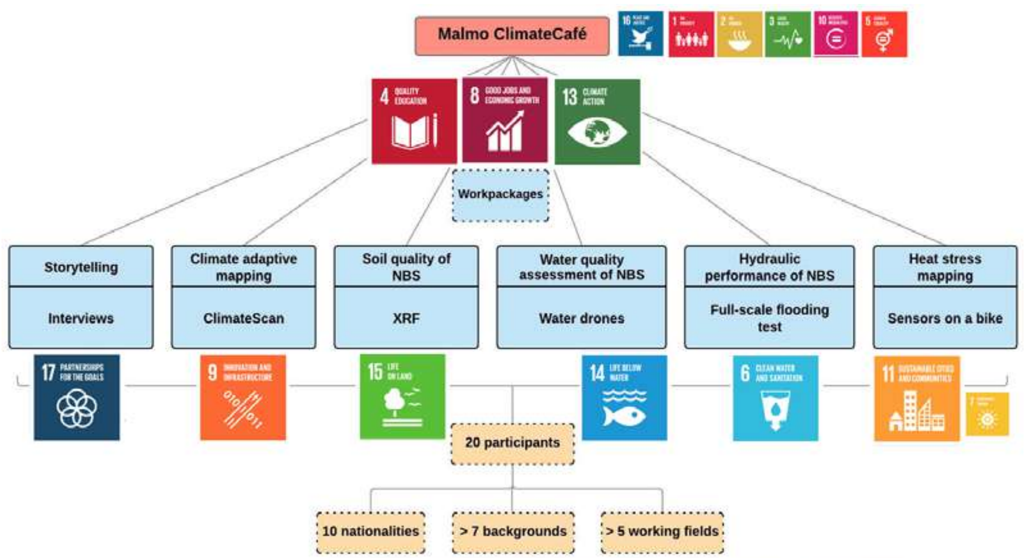


Figure 3. Flowchart of workshops included in ClimateCafé Malmö, which are related to the UN's Sustainable Development Goals (SDGs).

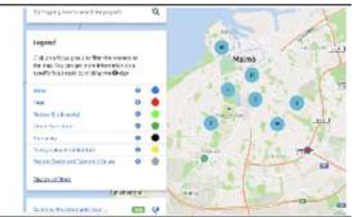
	Workshops	Workshop aim	Method	
1	Storytelling	To enhance discussions regarding climate adaptation UN SDG #17: partnership for the goals, #4: quality education, #11: sustainable cities and communities	Interviews with ClimateCafé participants, different stakeholders (government, industry, academia, and civil participants) and inhabitants of Augustenburg brought multidisciplinary viewpoints together and created new shared values that benefit Augustenborg to optimize the ecosystem services.	
2	Mapping climate adaptation on ClimateScan	Mapping of existing urban resilience projects and sustainable climate adaptation. UN SDG #13: climate action, #11 and #9: innovation and infrastructure.	Climate adaptations were mapped on the open-source tool www.climatescan.org	
3	Soil quality of NBS	To assess the built-up of potential toxic elements in the NBS in the study area UN SDG #6: clean water and sanitation, and #15: life on land.	A portable X-ray fluorescence (pXRF) instrument was used to measure the build-up of potential toxic elements (PTE) in the topsoil of rain gardens and swales after 20 years. A new method for cost-effective insights into the environmental performance of NBS.	
4	Water quality assessment of NBS	To scan water quality in this neighbourhood, and gain insights into the spatial variability of water quality between different ponds. UN SDG #14: life below water and #6.	The (surface) water quality of all ponds in Augustenborg was measured by underwater drones with cameras and sensors.	
5	Hydraulic performance of NBS	To gain more insight into the hydrological performance of NBS in the study area. UN SDG #6 and #13	Full-scale testing of swales was conducted using sensors, resulting in detailed measurements of the infiltration capacity of these nature-based solutions	

Table 2. Methods of the ClimateCafé Malmö workshops.

Methods and Results

Storytelling

Method: Storytelling

Storytelling, by the means of interviews, is a way of collecting data from participants of Climate-Cafe and citizens of Augustenborg. This creates engagement at a local level for topics such as climate adaptation (Moezzi *et al.* 2017). Storytelling has already been proven as an effective tool to discuss and build capacity among climate change (Harper *et al.* 2012).

Several residents of Augustenborg and every ClimateCafe participant was interviewed and recorded regarding the different topics in the workshops. The footage was analysed and cross-checked with post questionnaires sent online to the same participants to check how ClimateCafé is helping to build capacity related to climate adaptation (figure 4).

Results

Table 1 summarizes the origin and background of participants in ClimateCafé Malmö, as well as their knowledge about climate adaptation and how ClimateCafé may help them raise their awareness. The views of the participants were published in detail in the scientific journal Sustainibility (Boogaard *et al.* 2020) on the evaluation of ClimateCafe method itself, so the focus in this chapter is on the conducted semi-structured interviews with inhabitants of Augustenborg.

Talking to several young people playing near their school showed that most of them are aware of the basics of the water system in Augustenborg. They can show how the water will run during heavy rainfall from the (green) roofs to the gutters into the water-squares and bio-swales. Besides being aware of the hydraulics of the systems they also are in some extend aware of stormwater quality issues 'I will not swim in the water-square due to pollution'.

This knowledge base is partially due to the fact that their parents were involved 20 years ago in the reconstruction of Augustenborg. Also, the visibility of the surface water system can help explaining the insights of the inhabitants. An employee of the Green Roof Institute remembers the 31 August 2014 when Malmö was hit with about 100 mm of rain in 3,5 hours and remembers flooding in several places in the city but didn't recall any severe problems in Augustenborg.

Figure 4. Storytelling at the Green Roof Institute with Helen Johansson (Sweden) and Ana C. Cassanti (Brazil) on a green roof in Augustenborg.

Mapping of climate adaptation measures

Method: Mapping with the ClimateScan tool

To collect, distribute, and share knowledge, the open access, web-based ClimateScan adaptation tool www.climatescan.org was used. This tool helps policymakers and practitioners to gather valuable data for a rapid appraisal at the neighbourhood level, mapping specific climate adaption measures at specific locations with information. ClimateScan is a citizen science tool giving the exact location, website links, free photo, and film material on measures regarding climate mitigation and adaptation. NBS related to stormwater infiltration, such as swales, rain gardens, water squares, green roofs, and permeable pavement are some that improve the liveability in cities as presented at international seminar 'Cities, rain and risk', in Malmö (Boogaard *et al.* 2019).

Results

During the two days, over 175 NBS were mapped on www.climatescan.org (Figure 5) by the participants through uploading with the ClimateScan App in the field. The mapping included a short description, the location (GPS), category of NBS, and pictures. For some locations, additional information, documents, and websites for further information were added later using a computer.

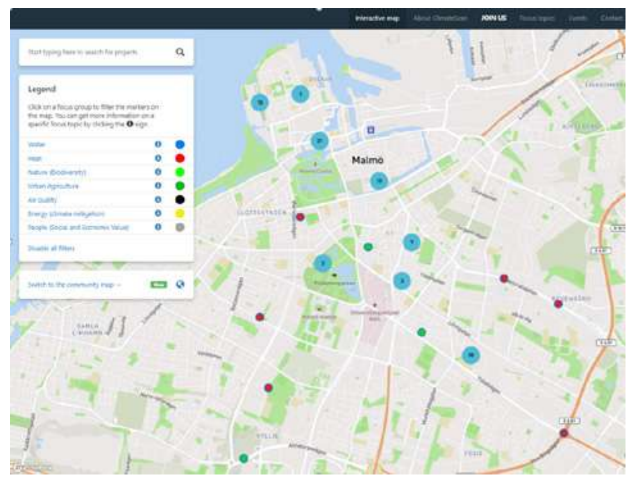


Figure 5. ClimateScan for Malmö city: more than 175 NBS mapped (from which 87 in Augustenborg) on the open-source nature-based solution platform www.climatescan.org.

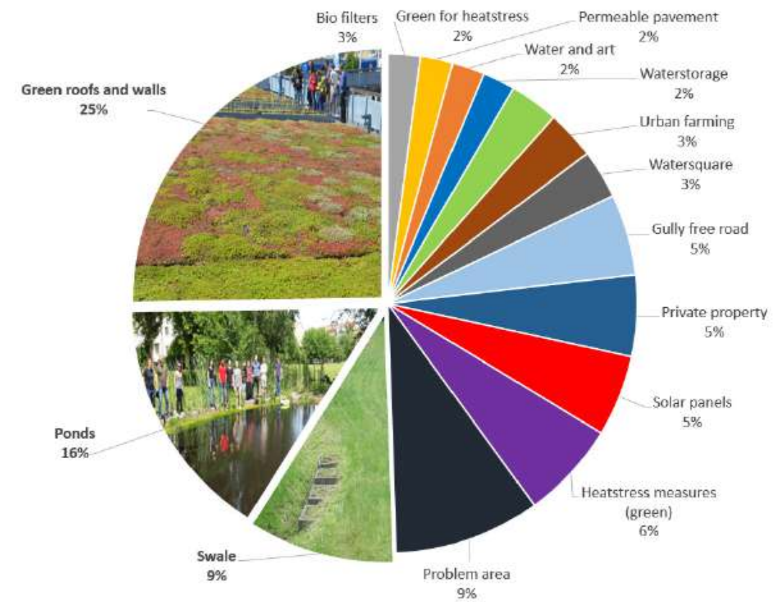


Figure 6 shows the results of the NBS mapping in Augustenborg (87) with high percentages on green roofs and walls (25%), ponds (16%) and swales (9%) covering half of the mapped NBS.

The mapped climate adaptation solutions in Malmo (175) were distributed in 19 categories, with the majority within the green roofs and walls category (26%). The following categories were bio filters (14%), rain gardens (12%), and ponds (9%).

Soil quality of NBS

Method: Quick scan mapping of pollutants with the use of portable XRF

NBS are constructed to receive, store, and infiltrate surface water to restore the groundwater balance and to remove pollutants. After 20 years of operation, build-up of pollutants is expected (Jones and Davis 2013). Therefore, the mapping of potential toxic elements in several NBS at Augustenborg is vital knowledge for stormwater managers that can be incorporated into management and maintenance.

The portable XRF (X-ray fluorescence) was used to map PTE (Figure 6). pXRF is an instrument that analyses the content of elements from magnesium (Mg, 12) to uranium (U, 92) in the periodic table. As stormwater is the transporting media of the pollutants the profiles of measurements must cover the inlet(s), the deepest part, and, if possible, the outlet(s) of the swale to map the distribution. For a systematic mapping of the dispersion of PTE in swales, measurements at a predetermined interval along profiles were conducted. Since the profiles were relatively short (max. 2 meters), the measuring intervals were from 0.2 to 0.5 meters. Each point was measured for 60 seconds, and the values displayed on the screen as well as stored for a later download from the instrument (Venvik and Boogaard 2020).

Figure 7. Quick scan mapping with portable XRF (X-ray fluorescence).

Results

The mapping of the PTE lead (Pb), zinc (Zn), and copper (Cu) in the large swale behind Augustenborg school by pXRF shows that the highest concentration of PTE was at the inlets and the deepest part of the swale. This is as expected since these are the areas in the swale most exposed to surface water in frequency and duration. All measurements were well below the Swedish thresholds for lead (80 ppm (mg/kg)), zinc (350 ppm), and copper (100 ppm) (Naturvårdsverket. 1997) and are thereby not polluted. After 20 years in operation, the NBS at Augustenborg shows a little build-up of PTE. This is most likely due to the absence of polluting source(s), such as no or little traffic, separate drainage system from the surrounding areas, thereby no drainage from major roads, industrial areas, or brownfields. This has not been the case in other residential areas after 20 years of operation, where PTE in the topsoil exceeded quality guidelines (Venvik and Boogaard 2020).

Water quality

Method: Measuring water quality using Remote Open Vehicles (ROV)

There are multiple ponds located within the district of Augustenborg, which collect and store rainwater. Literature often argues that the implemented measures reduce water quality degradation and that they have inclusively contributed to the improvement of the surface water quality (Boogaard *et al*. 2014). However, little is known about the water quality conditions of these small water bodies, as only a few studies have addressed water quality directly, and they mostly focus on the discussion of runoff water quality from green roofs in the area (Naeem 2010).

In order to map the spatial distribution of water quality parameters in the ponds, multiple sensors were attached to an aquatic drone (de Lima *et al* 2020) (Figure 7), which was then piloted across the ponds. A global positioning system (GPS) logger was also installed on the drone to record the coordinates of each measurement. The measurements took place on June 11th, 2019, after scattered rain events.

Results

Some ponds were clearly less turbid than others, as confirmed in the data collected. In most ponds, dissolved oxygen concentrations were above the minimum values required to sustain aquatic life

Figure 8. Demonstration of the water quality measurement campaign by Rui de Lima (Portugal) and Allard Roest (The Netherlands) with an aquatic drone in a pond.

(5mg/l). In three ponds dissolved oxygen reached values under this threshold (figure 8). The lowest value recorded corresponded to a location where a wastewater outlet was present (discharged water from washing machines, after passing by a small water treatment unit) and was measured in a small channel before it gets diluted in a pond. Chlorophyll-a and phycocyanin (cyanobacteria/blue-green algae) reached very high concentrations in a few ponds, which could become a threat to local populations. Results of turbidity measurements are in accordance with the other parameters measurement: when water is more turbid, algae concentrations and electrical conductivity are also higher.

Hydraulic efficiency of swales

Method: Measuring the hydraulic efficiency of swales using waterheight loggers

Bioretention swales are one type of NBS that has been used for decades globally to provide stormwater conveyance and water quality treatment (Woods Ballard *et al* 2015). Swales are a landscape surface-drainage system planted with vegetation that collect rainwater and allow surface runoff to be detained, filtered, and then infiltrate into the ground. The aim is to reduce peak flow, collect and retain water pollution, and improve groundwater recharge. However, one common issue is that swales can be subject to clogging (Boogaard 2015).

After mapping multiple swales in Augustenborg data were collected on the hydraulic conductivity and infiltration capacity using wireless, self-logging, pressure transducer loggers as the primary method of measuring and recording the reduction in water levels over time. Two loggers were installed at the lowest points of the swale. The transducers continuously monitored the static water pressure at those locations, logging the data in internal memory. To calibrate and verify the transducer readings also hand measurements, underwater cameras and time-lapse photography was applied (Figure 9).

Results

The test on the hydraulic performance of swales was performed after 20 years of operation. The results showed that all three swales are able to empty their water storage volume within 48 hours. The saturated infiltration capacity is thereby in the order of 0.15 m/d and 0.2 m/d (Table 3 and Figure 9).

These values are comparable to values found on the infiltration capacity of Dutch and German swales monitored after 10 to 20 years (Le

Figure 9. Discussion during swale monitoring with Floris Boogaard (The Netherlands) in Augustenborg.

	Logger	Slope	R2	k (cm/min)	k (m/d)
Swale 1	Logger 1	−21.804	0.9594	0.0174	0.23
Swale 1	Logger 2	−24.571	0.9702	0.0155	0.20
Swale 2	Logger 1	−15.824	0.9865	0.0112	0.15

Table 3. Hydraulic performance of two swales after 20 years.

Coustumer *et al.* 2012, Ingvertsen *et al.* 2011). The results show that these swales are considered sustainable after 20 years, with sufficient infiltration rate to infiltrate the stormwater in Augustenborg without any other maintenance than mowing the grass.

Conclusions

The results of the different workshops show that valuable multidisciplinary data can be gathered in a short period of time, which can be used by local stakeholders to improve, maintain, or evaluate the effectiveness of nature-based solutions in their local context.

Evaluation results show that the selected green infrastructure have a satisfactory infiltration capacity and low values of potential toxic element pollutants after 20 years in operation. In contrast, the study has shown that the blue infrastructure in Augustenborg requires further research and monitoring, as in some ponds the algae (blue-green algae) and dissolved oxygen concentrations revealed undesired values, which could have negative implications for inhabitants and animals in contact with the water.

The results of this study regarding quick scan mapping of pollutants and hydraulic test of nature-based solutions could help (storm) water managers with planning, modelling, testing, and scheduling of maintenance requirements for swales, raingardens and ponds with more confidence so that they will continue to perform satisfactorily over their intended design lifespan.

Long term lessons learnt from Augustenborg will help stormwater managers within planning of NBS. Lessons learned from this ClimateCafés will improve capacity building on climate change adaptation in the future. Furthermore, this chapter offers a method and results to prove the German philosopher Friedrich Hegel wrong when he opined that “The only thing we learn from history is that we learn nothing from history.” Let’s learn from Augustenborg.

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