Developing Small-Scale Green Rainwater Management Solutions for Amager

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Abstract

Climate change has exacerbated flooding by increasing the intensity and frequency of rain in Copenhagen. The city's districts of Amager Øst and Amager Vest experience damages due to excess rainfall and uniformly low elevation. In order to decrease runoff without replacing the old sewer system, the municipality is encouraging residents to manage rainwater locally. The installation and use of green solutions to reduce rainwater runoff can also encourage community interaction. For this project we designed a green plan for a courtyard in Islands Brygge, a neighborhood in Amager Vest, to serve as a model for other housing complexes. In addition, to encourage other residents to utilize green strategies, we designed two webpages to make our research and design accessible to the public.

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Executive Summary

Due to climate change, the amount of everyday rain and extreme weather events have increased in Copenhagen, and will continue to do so in the future. The city currently experiences 40 to 50 mm of rain per month, and the intensity of rainfall is expected to increase by 20% to 50% by 2100 (Holiday Weather, 2016; The City of Copenhagen, 2011). These projections could be problematic for Copenhagen as an urban area with uniformly low elevation. In July of 2011, a cloudburst released 135 mm of rain in three hours, causing damage worth DKK 6 billion (Kilhof, 2014). As a result, the city created the Climate Adaptation Plan in 2011 and Cloudburst Management Plan in 2012 detailing methods for managing excessive rainfall. Instead of expanding the old sewer system, which is a gray rainwater management method because it is inflexible and combines wastewater and stormwater runoff, large portions of these plans focus on reducing rainwater runoff locally (Voskamp & Van de Ven, 2015). These ideas include using canals and basins to collect and drain water or to lead it into the harbor (The City of Copenhagen, 2012). They also propose that rain be managed using green rainwater management strategies such as green roofs and rain gardens, which are flexible methods that can adapt to the local climate, use water as a resource, and benefit the environment (The City of Copenhagen, 2011). Not only can these strategies be implemented on a small-scale by individual homeowners rather than citywide, but they are also less expensive than replacing the sewer system.

Our project's sponsor, Miljøpunkt Amager, is an independent, nonprofit organization that promotes environmental sustainability in the Copenhagen districts of Amager Øst and Amager Vest. In addition to working on projects involving compost, bike sharing, and urban agriculture, the organization educates residents about how they can participate in climate adaptation (Miljøpunkt Amager, 2016b). They not only consider the environmental impacts of the project, but their potential to build community, especially within housing complexes and other shared spaces.

This project was designed to determine possible cost-effective green rainwater management solutions to be implemented by residents in Amager. Our objectives for this project were to:

1. Evaluate green rainwater management techniques to recommend to Amager citizens
2. Collaborate with a model community to design a green rainwater management plan
3. Determine community members' attitudes toward green rainwater management strategies
4. Create informational webpages to encourage residents to implement green rainwater management strategies in Amager

We first determined which green strategies were feasible for residential structures in the area. We accomplished this through literature research, observations of common building characteristics in Amager Øst and Amager Vest, and interviews with individuals familiar with green strategies. To apply these strategies to a specific location, we collaborated with a housing complex in Islands Brygge to design green elements for their courtyard that would reduce runoff and improve the usability of the space. After visiting the area and discussing ideas with courtyard committee members, we created an initial plan complete with calculations of costs and water retention during a 10-year rain event, as well as a 3D visual created with Revit, an architectural modeling software. We then refined it based on input from the committee and proposed a final design option to be presented to the housing board. Since the

municipality aims to increase resident participation in climate adaptation to 30%, we assessed their current attitudes towards green rainwater management directly through an online survey and by discussing community involvement with Miljøpunkt Amager employees and volunteers (L. Nygaard Arre, February 8, 2016). To educate residents of Amager, we compiled information about green techniques into two webpages on Miljøpunkt Amager's website, providing them with descriptions, costs, and water retention values for each strategy, as well as visuals from the courtyard design.

After observing residential properties in Amager Øst and Amager Vest, we were able to identify which green strategies would be feasible based on common elements and structural requirements. Many of the single or multi-family homes contained yard space for rain gardens and small sheds or garages ideal for green roofs. In housing complexes, many courtyards already included some green space but could be improved for better rainwater management and community interactions; for example, the roofs of trash and recycling container sheds could be adapted with green roofs and open impervious surfaces could be adapted to better manage rain with flower beds, planters, or other green elements.

We applied the information gained from literature research and interviews to the specific courtyard in Islands Brygge. After viewing the space and discussing ideas with courtyard committee members Anders Bo Peterson and Andreas Zacho, we modeled the current layout of the courtyard, seen in Figure 1 below, and a preliminary rainwater management design. In order to quantify the different strategies included in the design, we calculated the water retention potential in a 10-year rain event (defined as 50 mm of rain over the course of a few hours) and cost of each element (Rivas, Cremer, McCann, & DeCicco, 2013). We estimated, based on retention values and capacities of each strategy, that all solutions would be capable of fully retaining average daily volumes of rain.

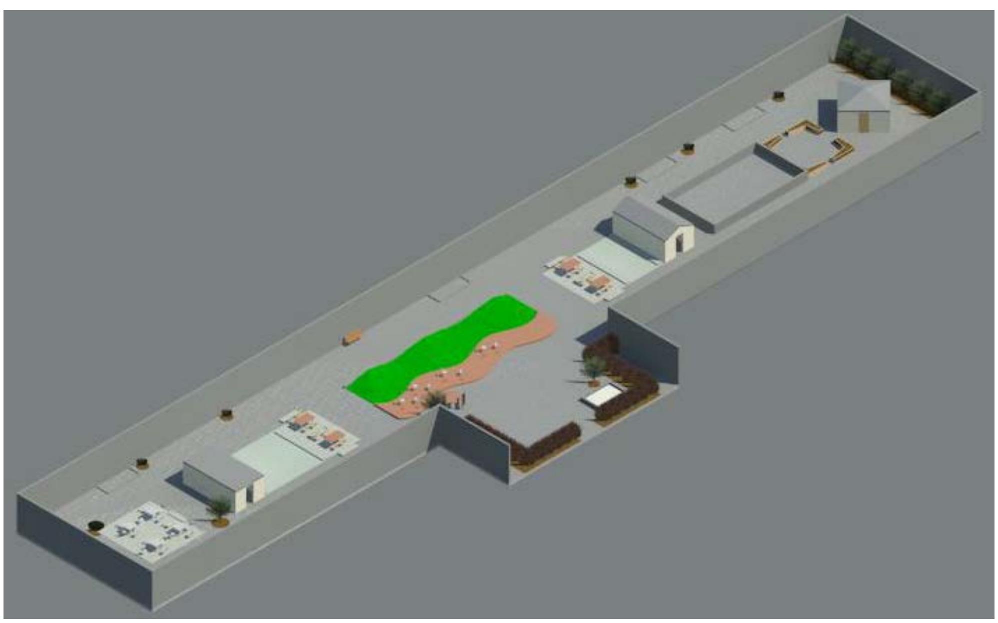

Figure 1: The current layout of the courtyard.

Using feedback we received from the committee members on our initial design, we generated a list of possible solutions as well as two example designs that incorporated some of those strategies. From that list, the committee members selected different strategies they wanted to include in the rainwater management plan for the courtyard. We then combined their selected strategies into our final design, shown below in Figure 2. This design includes green roofs, flower beds, planters, an herb garden, a bike planter, additional extra green space, and rain barrels that would cost in total DKK 102,519. The estimated total water retention for this design during at 10-year rain event is 13,142 L, 15.30% of the total rainfall that falls on the courtyard. These numbers only account for the retention of rainwater that falls directly onto the adapted surfaces, and does not include runoff from impervious surfaces that may flow into green spaces or flower beds.

Figure 2: Final courtyard design (completed April 27, 2016).

Using research that we gathered throughout the project, we created two webpages to educate the general public about green rainwater management. Our pages were added to the Climate Adaptation portion of Miljøpunkt Amager's website; they detail our research information and describe our design for the model housing complex courtyard to guide users in selecting their optimal green rainwater management solutions. We designed the pages using the information that we gathered from interviews with experts and responses to the survey we included in Miljøpunkt Amager's newsletter. The first webpage features an infographic summarizing the cost, efficiency, and function of each strategy. It also includes descriptions and pictures of each strategy, as well as a short explanation of the courtyard design and a link to the second page detailing the design. The second page contains a visual of the final design and descriptions of each strategy that was incorporated.

The design and calculations used for this specific case can serve as a model for other courtyards, allowing our sponsor to provide other complexes with information about how they may adapt their similar spaces in a green and community-centered way. These designs, along with more general information about different strategies, will be available on Miljøpunkt Amager's website for future use by residents. Therefore, these deliverables are tools that our sponsor and other community members can use to propose plans for other courtyards while also providing information for future climate adaptation projects.

Authorship

This section describes the roles of each student in the development of this report. All members performed literature research and contributed to the tasks of drafting, revising, editing, and formatting.

Allison drafted the Background sections detailing case studies of green rainwater management and the social perspective of climate adaptation. She also drafted the first objective in the Methods, the Conclusion, and parts of the Results and Introduction. She also focused on editing and formatting the figures and graphics.

Alexandra researched and drafted the Background sections detailing green rainwater management strategies and their advantages over traditional methods. She also drafted the third objective in the Methods, significant portions of the Results, and parts of the Introduction. She also focused on revising the report to help the ideas flow and editing for grammar and style.

Daniel researched and drafted the Background sections comparing gray and green rainwater management and the advantages of green methods. He drafted the fourth objective in the Methods and parts of the Introduction and Results. He also focused on creating the courtyard designs in Revit, formatting tables, and revising.

Jarrod researched and drafted the Background sections detailing the environmental challenges caused by climate change. He also drafted the second objective in the Methods and parts of the Results and Introduction. He then focused on editing and making sure the figure and table numbering was consistent.

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Introduction

Due to the growth of industry, climate change has become an undeniable issue that we all must face. The increase in average temperatures can have a large effect on human health by contributing to the spread of diseases, disrupting food production, and causing an increase in extreme weather events (World Health Organization, 2015). This temperature increase causes the polar ice caps to melt at an accelerated rate, raising the sea level and causing additional flooding and damage to coastal cities. In addition to increased temperatures and coastal floods, climate change causes an exaggeration of existing weather patterns. For areas that currently experience significant rainfall, the Intergovernmental Panel on Climate Change has predicted an increase in the frequency and intensity of precipitation, in addition to an increase in the frequency of extreme weather events (Intergovernmental Panel on Climate Change, 2014).

One such area is Denmark, which has uniformly low elevation with little variation across the terrain. Specifically, the island of Amager, which contains a portion of the capital city Copenhagen, has an average elevation of less than 10 m and most of the area is only about 3 m above sea level (Flood Map, 2014). Since Amager is urban and mainly residential, the constant rain and flooding are significant problems for property owners. Copenhagen experiences on average 40 to 50 mm of rainfall and 15 to 20 days with rain every month (Holiday Weather, 2016). Denmark is also prone to cloudbursts, a weather phenomenon in which 15 mm of rain falls in 30 minutes or less (Dreehsen, 2011). The most recent severe cloudburst occurred in 2011, when 135 mm of rain fell in only 3 hours (Kilhof, 2014). The resulting flooding caused around DKK 6 billion (1.04 billion USD) in damages to the city of Copenhagen, with more than half of residents experiencing some form of damage to their homes (Gerdes, 2016). Due to poor management of the water and the overflow of the drainage systems, the excess water flooded into residents' basements and led to one death due to pollutants from the sewers (Kilhof, 2014). With the threat of more flooding as a result of climate change, the people of Denmark must become more involved in improving their rainwater management systems; once citizens take the initiative on this issue, more solutions can be put in place to further prevent infrastructural damages.

In order to mitigate the additional runoff from flooding, Copenhagen has predominately worked to manage rainwater on the citywide level. In 2011, the city released the Copenhagen Climate Adaptation Plan, which presents strategies to protect Copenhagen from environmental challenges related to climate change, such as increased rainfall (The City of Copenhagen, 2011). The Cloudburst Management Plan of 2012 builds off the previous report with a focus on flood prevention from both everyday rain and extreme rainfall events such as cloudbursts. Many of the strategies described in both plans include citywide measures, largely involving modifications to the sewer system. In addition, the plans outline methods to store and then drain rainwater at ground level in areas such as basins and canals. This would divert excess rainwater away from the sewer system, reducing overflow (The City of Copenhagen, 2012). However, the Copenhagen Technical and Environmental Administration estimates that the amount of additional water could not be completely managed by the open spaces above ground (The City of Copenhagen, 2012). Instead, additional strategies are required to reduce stress placed on the sewer system during extreme rainfall events by decentralizing water management. Such solutions that would also benefit the environment by reducing runoff and pollution are considered blue-green (also referred to as green) rainwater management strategies (Voskamp & Van de Ven, 2015). These solutions integrate water management with the local ecosystem to store and filter water, reduce runoff, recharge groundwater, and cool structures (Voskamp & Van de Ven, 2015). They include green roofs, rain gardens, bioswales, planters, flower beds, green spaces, and rainwater storage containers. These strategies have been implemented successfully around the world with rain gardens in Seattle, rain barrels in Philadelphia, and green roofs in Germany and China (Seattle Public Utilities, 2009; *Soka-Bau Green Roof Case Study*, 2004; Walshe, 2013; Q. Zhang et al., 2015). These solutions have become more widespread in Copenhagen; in 2010, the city issued a mandate requiring all new buildings with roofs with less than a 30 degree incline to include green roofs (Merchant, 2010). Green solutions are especially relevant to Copenhagen as property owners can easily integrate them into the urban landscape as small-scale climate adaptation strategies.

Miljøpunkt Amager, a nonprofit, nongovernment organization operating in the Amager Øst and Amager Vest districts in Copenhagen, works with local community members to advance green and sustainable practices. The organization has projects focused on waste prevention, transportation, and networking citizens with each other to promote sustainability (Miljøpunkt Amager, 2016b). Recently, the organization has focused on climate adaptation and providing information for property owners on how to manage rainwater for single-family homes, but there is little information regarding adapting housing complexes or additional benefits of green solutions (Miljøpunkt Amager, 2016a). The Copenhagen government intends to increase the number of residents participating in climate adaptation to 30% of the population (L. Nygaard Arre, personal communication, February 8, 2016). Citizen involvement is necessary to adapt Copenhagen's rainwater management as 60% of roads are privately owned (L. Nygaard Arre, personal communication, February 8, 2016). Since Miljøpunkt Amager is largely focused on the interests and opinions of the people of Amager, our project aimed to expand the organization's resources to better educate the community about green rainwater management, as well as the co-benefits such as community interactions.

This project was designed to investigate possible cost-effective green rainwater management solutions to be implemented by residents in Amager. We began by evaluating which green rainwater management techniques should be recommended to the Amager citizens. To accomplish this, we interviewed individuals involved in green rainwater management and observed buildings throughout Amager to determine which solutions are more likely to be successful. To apply these strategies to a specific location, we collaborated with a model community in Islands Brygge to design a green rainwater management plan for their housing complex courtyard that would both reduce runoff while facilitating community involvement between the residents implementing and using the green solutions. We created visuals of our design for the residents and used the feedback from courtyard committee to modify the design and make recommendations for its implementation. We also investigated the attitudes of community members of Amager toward green rainwater management strategies through interviews with experts and an online survey. Finally, we compiled information from interviews, the survey, observations, and existing literature to create two webpages informing Amager residents as to the benefits of green rainwater management and characteristics of various strategies. Together these objectives contributed to the goal of increasing awareness of green solutions that residents of Amager can employ to reduce runoff caused by excess rainwater, specifically in housing complexes.

Background

Climate change is a global issue that countries around the world have acknowledged and are attempting to mitigate. As a consequence of anthropogenic climate change, more rain has fallen in Copenhagen and the surrounding countryside in recent years. In Denmark, uniformly low elevation results in susceptibility to flooding, especially in urban areas due to the prevalence of impervious surfaces.

Environmental Challenges Exacerbated by Climate Change

Changes in rainfall, temperature, and the urban heat island effect pose health and economic problems around the world. There is mounting evidence to indicate a causative connection between rising anthropogenic carbon dioxide levels and increasing temperatures (The City of Copenhagen, 2011; World Health Organization, 2015). The Intergovernmental Panel on Climate Change (IPCC) predicts that the global mean temperature average will increase by 3^{o}C over the next century (The City of Copenhagen, 2011). The increase in temperature will cause cities, like Copenhagen, to be further affected by the urban heat island effect. Urban heat island is a measure of the air temperature of a city at the ground level; the surrounding buildings and various gases in the air trap the heat in the city, making the air temperature warmer than less developed surrounding areas. This excess heat can make it difficult for people to maintain an ideal body temperature and can make them more susceptible to illness (The City of Copenhagen, 2011). Consequently, the urban heat island effect results in higher electricity consumption in warmer months as people attempt to cool their work places and residences (Akbari, 2005). In addition, the urban heat island effect increases smog production, as the higher temperatures cause increased humidity and aerosolization of pollutants (Akbari, 2005; VanMeetren, 1999).

In addition to increasing temperatures, the IPCC predicts that the annual volume of rain will increase. Copenhagen experiences 15 to 20 days of rain per month, totaling 40 to 50 mm of rainfall from everyday rain events (Holiday Weather, 2016). In addition to this typical rainfall, there are 10-year rain events which total about 50 mm in a few hours and 100-year rain events totaling over 100 mm in the same time (Rivas et al., 2013). Copenhagen also experiences cloudbursts, extreme rainstorms in which 15 mm of rain fall in 30 minutes or less (Dreehsen, 2011). In addition, the IPCC expects the intensity of the rain to increase between 20% and 50% (The City of Copenhagen, 2011). According to Mads Popowitz from the Rain and Sewage Department of HOFOR, an organization that connects the municipality with citizens and consultants to establish large-scale water management systems, when predicting rain events in Copenhagen the estimated intensity and volume of rainfall is calculated by multiplying the current rainfall statistics by a climate factor of 1.3 to 1.56 for 10 to 100 years in the future. The storm is graphed based on the Chicago Storm Design, where intensity of the storm follows a left-skewed normal curve (M. Popowitz, personal communication, April 12, 2016). The current sewer system in Copenhagen is not prepared to handle this drastic increase in pluvial and fluvial water. This results in water overflowing the drainage system and pooling in natural low points of the land. It is possible, through planning, to direct the floodwater into places where little damage will be caused such as parks, open spaces, and sports grounds (The City of Copenhagen, 2011). Even with these adjustments to the water management system, the Copenhagen Technical and Environmental Administration calculated that the increasing quantity of rain cannot be successfully stored in the open spaces of the city (The City of Copenhagen, 2012).

Infrastructural Damages from Flooding

Large amounts of flooding lead to serious infrastructure concerns. For example, in July 2011, a cloudburst hit Copenhagen, flooding the city with 135 mm of water in only three hours (Kilhof, 2014). Water poured into residential basements, streets, and major roads. The damage from the flood amounted to DKK 6 billion (1.04 billion USD), with 61% of the citizens of Copenhagen experiencing water damage to their property (Gerdes, 2016). This event occurred only a year after a similar cloudburst that caused irreversible damage to homes and infrastructure in the city. Compared to the years leading up to and following the two cloudbursts, damage from rain events has been significantly less, as seen in Figure 3 below. The two severe cloudbursts of 2010 and 2011 prompted Copenhagen's government to develop a plan to supplement the existing sewer system with an above ground water system that combines infrastructure with waterways, as well as stores water in parks and fields when necessary. This strategy aims to keep the water that is above ground clean and prevent it from entering the sewer system where it will be both contaminated and discarded. Due to the cost of this system, experts suggest the addition of small-scale, local management of rainwater (Kilhof, 2014). Local management also allows rainwater to be used as a resource.

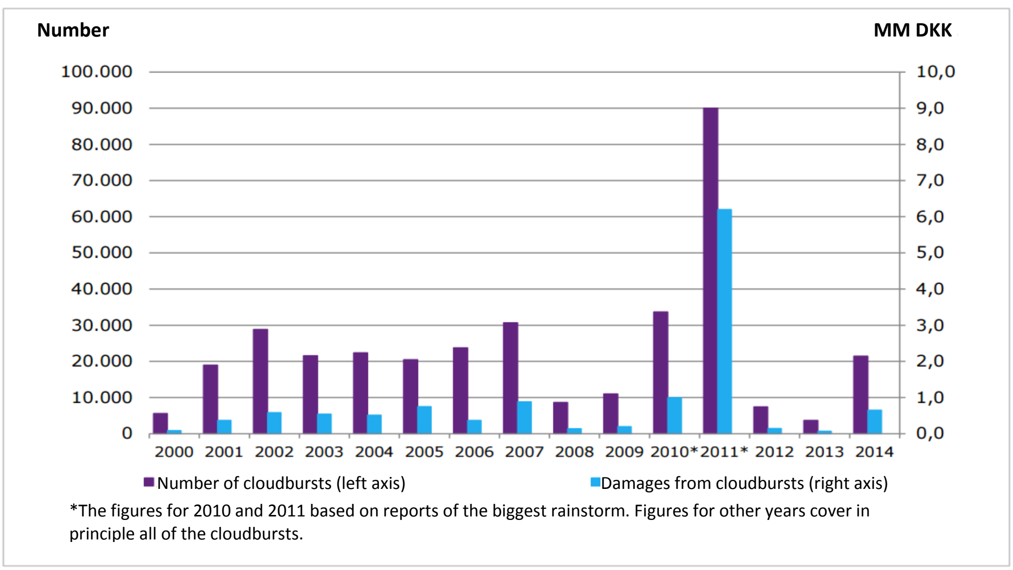

Figure 3: Graph of cloudburst damage in Denmark from 2000 to 2014. Translated from Forsikring & Pension (2015).

With the changing climate, houses and other buildings must be adapted to handle extremes of the current weather patterns. Extreme weather events and changes in rainfall and temperature patterns are already occurring, but homes are not appropriately outfitted. There are several weather related damages that are expected to occur more frequently in the short term. With an increase in rain, leaks in basements, through roofs, and into walls that are not properly sealed are the primary concerns. In addition, water backflow, when water comes up through floor drains in basements, could occur if sewer systems are unable to handle the rate of rainfall. Mold, mildew, wood rot, and stone fracturing cause further structural issues in residential areas due to the higher humidity resulting from an increase in temperature and rainfall (Glaas, Neset, Kjellström, & Almås, 2015). While these concerns are for warmer months, when the weather is below freezing an increase in precipitation would result in heavy snowfall. With climate change, excessive weight on roofs, creation of ice sheets and ice dams, and water damage from melting snow or ice are all concerns related to cold weather for underprepared households (Glaas et al., 2015). Houses that are most at risk for flooding are those in heavily paved areas, near water sources (for example along coastlines), or in areas in the city with low elevation (Glaas et al., 2015). These characteristics promote the accumulation of rainwater runoff and prevent it from draining into the ground away from structures.

Pollutants in Rainwater Runoff

In addition to concerns related to damages caused by flooding, pollutants can be absorbed and transmitted by the excess rainwater that has become prevalent in Copenhagen. Lykke Leonardsen, head of the City of Copenhagen's Climate Unit, stated in an interview that one death occurred from the 2011 cloudburst from rat urine in sewage water overflow and shows "why it's necessary … to implement a citywide cloudburst management system" (Kilhof, 2014). Another type of contamination that can be transmitted through excess rainwater is air pollution; atmospheric deposition results in atmospheric pollutants transferring into both aquatic and terrestrial ecosystems (Sánchez, Cohim, & Kalid, 2015). According to Sánchez et al. (2015), atmospheric pollutants include, but are not limited to: "particulate matter contacting heavy metals, polycyclic aromatic hydrocarbons, dioxins, furans, sulfates, [and] nitrates" (p. 121).

There are multiple ways that these atmospheric pollutants can enter the water sources. Sánchez et al. (2015) identified three of the main types: dry deposition, occult deposition, and wet deposition. Dry deposition is the process of particles being carried by the air as they fall from the atmosphere onto surfaces and soil in urban areas in the absence of precipitation. Once on the ground rainwater runoff can pick up and carry these pollutants. Occult deposition involves water droplets deposited by fog, mist, or clouds, and only plays a significant role in areas that are frequently cloud covered. An example of this is occult deposition of sulfates and nitrates from an industrial area into the nearby forest by fog and rime (Sánchez et al., 2015). While occult deposition is not considered prominent in most urban areas, it could be harmful to Copenhagen with its many green spaces and frequent cloud cover. Lastly, wet deposition refers to the process of raindrops capturing air pollutants and transporting them to the earth's surface through precipitation (Sánchez et al., 2015).

The concentrations of pollutants in the water can have a significant negative effect on the ecosystem's health as well as water quality (Goonetilleke, Yigitcanlar, & Ayoko, 2014). For example, an increase in dissolved organic carbon (DOC) concentrations can make hyrdocarbons and heavy metals more soluble, resulting in the substances being retained more readily by stormwater runoff. According to Popowitz, runoff from roads with over 5,000 cars per day contains pollution levels too high for the water to be led directly into the harbor. Instead, the water is collected by sewers and led to the wastewater treatment plant, which can cause overflow (M. Popowitz, personal communication, April 12, 2016). This, in turn, exposes the environment to more pollutants, further increasing ecosystem and human health threats. In addition, intense rainfall has the ability to pick up greater concentrations of these pollutants (Goonetilleke et al., 2014). The transportation of these pollutants in various ways further affects the well-being of the surrounding areas. Pollutants cause excess stormwater to be non-potable, or unsafe for consumption and watering food crops, which limits the effective uses of the rainwater. If a rainwater harvesting method is able to clean the water it catches, then it can be used for watering plants with few health risks. Removing the pollutants and managing the water effectively will further prevent infrastructure damage and safeguard the health of the people and the surrounding ecosystem.

Comparison of Blue-Green and Gray Rainwater Management

Currently, most strategies used in Copenhagen to manage flooding and rainwater are considered gray solutions as opposed to blue-green solutions. Gray solutions include infrastructures, such as underground pipes, sewer systems, concrete elements, and pumps, that are considered inflexible (Voskamp & Van de Ven, 2015). Blue-green infrastructure, also referred to as green infrastructure when applied to rainwater management, includes structures such as green roofs, rain gardens, and green spaces that reduce runoff quantity and pollutant load (Voskamp & Van de Ven, 2015). While Denmark strives for environmental efficiency and consciousness, many gray solutions are already established, and although costly, are simply more efficient and easier to implement on a citywide basis.

The primary floodwater management strategy implemented in Copenhagen involves the use of the sewer system to collect rainwater and bring it to basins or treatment facilities. However, in its present state, "[t]he sewerage system lacks sufficient capacity to handle extreme rainfall events" (The City of Copenhagen, 2012). As a result, there is a possibility for backup in the sewers, and wastewater will sometimes overflow into the streets or flood through basement drains into residential homes (The City of Copenhagen, 2011). These issues are least concerning, as there are currently plans being made to reduce surface flooding that occurs once every ten years, and basement flooding can be easily prevented with the addition of a backwater valve by the homeowner (The City of Copenhagen, 2011). The main issue is that when the sewers approach their maximum capacity, safety valves need to be opened, which allows for the mixed rainwater and wastewater to be dumped into lakes, streams, and the harbor (The City of Copenhagen, 2011). As the amount of rainfall increases, these safety valves will be used more often, releasing even larger quantities of untreated wastewater into the already suffering lakes and harbor (The City of Copenhagen, 2011). During our interview with Popowitz, he explained how HOFOR has been partnering with the municipality and residential communities to co-finance the installation of large scale rainwater management systems, such as basins and artificial lakes, for rainwater storage in order to alleviate some of the stress on the sewer system and treatment facilities. However, large common areas are rare in some parts of Copenhagen, so this method of management will not be applicable to the entire city. This is forcing the continued use of more gray solutions involving new pipes that will carry rainwater directly to the harbor; however, this addition is extremely expensive and construction will be disruptive and time consuming (M. Popowitz, personal communication, April 12, 2016).

In the case of surface flooding, channels or sandbags are used to direct water to flat, open areas, like parking lots or recreational green spaces (The City of Copenhagen, 2012). This method of ground level storage is inconvenient, as areas used for storage cannot be used for their intended purposes until the water has drained. Meanwhile, much of the water may be absorbed into the ground, which can damage the structure of nearby buildings and roads over long periods of time (The City of Copenhagen, 2011). As rainfall is expected to increase due to climate change, this method of managing surface flooding will become ineffective; larger amounts of water that collect in these flat areas with low elevation will not be able to drain or disperse. This means that any water brought into these locations would need to be removed later (M. Popowitz, personal communication, April 12, 2016). The amount of runoff stored in these open areas can be reduced with the addition of small-scale rainwater management infrastructure. Such systems will provide more time to manage the surface runoff by storing it to delay the flow of water or for later use.

Advantages of Blue-Green Rainwater Management

While gray rainwater management techniques have been used most frequently, blue-green strategies provide an environmentally friendly alternative. Voskamp and Van de Ven (2015) distinguish gray from blue-green rainwater management in order to show how the latter can be effectively used in urban areas. Gray techniques are inflexible while blue-green techniques are designed to work with the local climate and vegetation to manage rainwater. These blue-green methods can be further described based on their functions: to store rainwater, reduce runoff, replenish groundwater, or cool structures. The addition of these blue-green solutions is also significantly less expensive than modifying preexisting gray solutions with larger pipes or additional pumping stations (M. Popowitz, personal communication, April 12, 2016).

Blue-green strategies include approaches that naturally separate water from waste in order to use the water as a resource. This approach was highlighted in green urban planning efforts taken in Taiwan and the Netherlands, where water was collected and stored to reduce runoff and only discharged if necessary (Schuetze & Chelleri, 2013). Other approaches, such as bioretention systems, are designed to filter stormwater of pollutants before it infiltrates into the groundwater (Charles River Watershed Association, 2008). The speed of infiltration is affected by factors such as water table location and soil composition. The water table is the depth underground at which the ground is saturated with water; once water infiltrates to the water table it is significantly slowed and eventually stopped (Perlman, 2016). Also soils high in clay, like those in many areas of Copenhagen, do not absorb water well (Perlman, 2016). These factors decrease the rate of rainwater absorption, causing an accumulation of surface runoff. In addition, the vegetation associated with green solutions can also reduce the temperature of structures; the Pennsylvania State University Center for Green Roof Research found that the surface temperature of green roofs was much more stable than those with traditional roofs, as seen in Figure 4 below (Technical Preservation Services, 2016a).

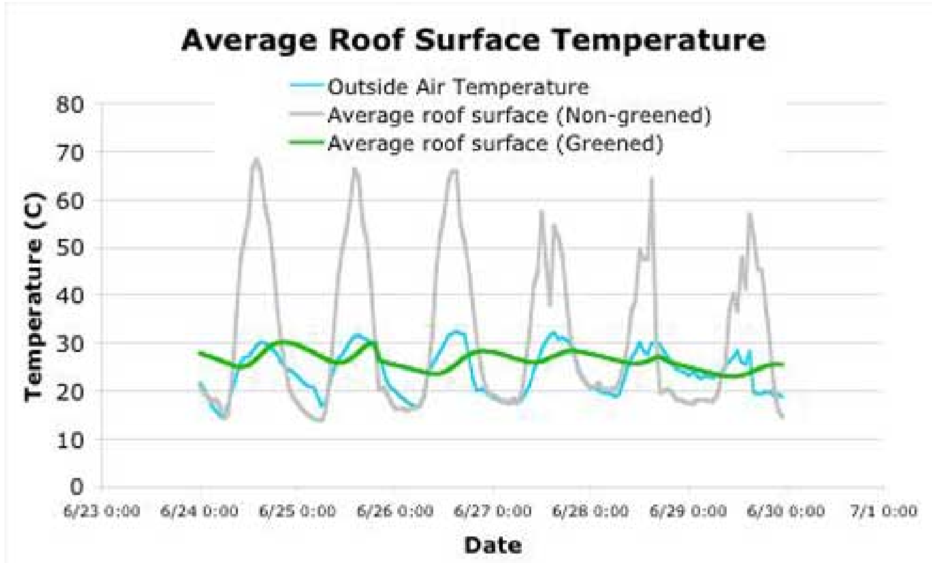

Figure 4: Roof surface temperatures of green and traditional roofs compared to air temperature (Technical Preservation Services, 2016a).

Many blue-green solutions are implemented as part of Sustainable Urban Development Systems (SUDS), low-impact development strategies, and best management practices, which manage rainwater on a larger scale while preserving the environment (Voskamp & Van de Ven, 2015; S. Zhang & Guo, 2012). In Copenhagen, the combination of gray and blue-green solutions is outlined in a 20-year plan to add a stormwater drainage system to the city roads (L. Nygaard Arre, personal communication, February 8, 2016). The drains would act as a way for excess floodwater from individual green rainwater management elements to be carried and dumped into the harbors to minimize infrastructural damage.

Examples of Effective Blue-Green Rainwater Management Solutions

Since gray rainwater management strategies alone can be ineffective and detrimental to the environment, blue-green solutions provide both large and small-scale alternatives. Small-scale elements, including green roofs, rain gardens, bioswales, green spaces, planters, flower beds, and rainwater storage containers, have been implemented alongside other solutions, both gray and blue-green, to reduce runoff and flooding around the world. For a summary of details pertaining to each strategy see the matrix in Appendix A.

One of the most prominent and effective blue-green rainwater management solutions is the green roof. A green roof is a layer of soil and vegetation located on a building's roof that helps reduce runoff and provide green space in urban areas (Lee, Moon, Kim, Kim, & Han, 2013). There are two types of green roofs: extensive green roofs, which contain a thin layer of soil covered in a grasses, mosses, or sedums, and intensive green roofs, which contain a thick layer of soil that can support shrubs and trees (for a more in-depth comparison of green roof types, see Table 1 below) (Voskamp & Van de Ven, 2015). Green roofs often contain a variety of plants that thrive in different conditions so that areas of the roof can adapt to sunlight and rain conditions. According to project coordinator Jann Kuusisaari from UrbanPlanten, a community garden area located on Amager, small extensive green roofs can be installed without special training or equipment. They can be built either from premade elements bought from professionals or basic materials that can be purchased from hardware stores; this makes extensive green roofs easy for homeowners to install on smaller buildings likes sheds and garages (J. Kuusisaari, personal communication, March 16, 2016). While extensive green roofs can be used to mitigate flooding by reducing runoff, intensive green roofs can also be engineered to collect water (Voskamp & Van de Ven, 2015). For example, in Almere, The Netherlands, green roofs were proposed as a way to both reduce runoff and collect rainwater. This was designed to decentralize stormwater flow and decrease stress put on citywide systems in the coastal area near sea level, much like Amager (Schuetze & Chelleri, 2013).

Table 1: Comparison of extensive and intensive green roofs. Borrowed from (Technical Preservation Services, 2016b).

Comparison of Extensive and Intensive Roofing Systems		
	Extensive Green Roof	Intensive Green Roof
Brief Description	▪ Thin soil, little or no irrigation, stressful conditions for plants	▪ Deep soil, irrigation system, more favorable conditions for plants
Advantages	▪ Lightweight ▪ Suitable for large areas ▪ Suitable for roofs with 0-30° slope ▪ Low maintenance ▪ Often no need for irrigation and drainage systems ▪ Relatively little technical expertise needed ▪ Often suitable for retrofit projects ▪ Can leave vegetation to develop spontaneously ▪ Relatively inexpensive ▪ Looks more natural ▪ Easier for planning authority to demand green roofs be a condition of planning approvals	▪ Greater diversity of plants and habitats ▪ Good insulation properties ▪ Can simulate a wildlife garden on the ground ▪ Can be made very attractive ▪ Often visually accessible ▪ Diverse utilization of roof (i.e. , for recreation, growing food, as open space."
Disadvantages	▪ More limited choice of plants ▪ Usually no access for recreation or other uses ▪ Unattractive to some, especially in winter	▪ Greater weight loading on roof ▪ Need for irrigation and drainage systems, hence, greater need for energy, water, materials, etc. ▪ Higher cost ▪ More complex systems and expertise required

Green roofs reduce both runoff and pollutant load in rainwater. A quantitative analysis of the effectiveness of extensive green roof systems was conducted by Lee, Moon, Kim, Kim, and Han (2013) in South Korea. The researchers found that green roofs contain four essential parts: "waterproofing, a drainage layer, a growing medium, and vegetation" (Lee et al., 2013, p. 258). To determine how efficient extensive green roofs are in urban areas, they considered variables such as the amount of overall precipitation, rate of precipitation during storms, rate of evaporation, and soil characteristics. One of the most significant metrics used is the catchment efficiency (CE), the ratio of the amount of rainwater runoff to the amount the roof was exposed to; the lower the value, the more effective the roof is at retaining water. The authors found that although extensive green roofs can become overloaded in extreme storm events with CE values near 0.9 like a typical concrete roof, under most rainfall conditions the roofs had CE values from 0.44 to 0.52 (Lee et al., 2013). Similarly, in China, Q. Zhang et al. (2015) found that extensive roofs reduced annual runoff by 27% to 81% and intensive green roofs ranged between 65% and 85%. The researchers also determined that on average the water acidity increased from 5.61 in initial rainwater to 6.84 in runoff water and the roofs acted as sinks for nitrates, ammonium, and metal ions (Q. Zhang et al., 2015). Furthermore, green roofs have been shown to contribute to a decrease in the urban heat island effect by covering dark colored roofs with plants that use evapotranspiration, which stabilizes the temperature of the roof (Technical Preservation Services, 2016a). These qualities show that both intensive and extensive green roofs can significantly reduce runoff from rain that falls on roofs and improve the urban landscape.

Rain gardens can also be used to mitigate runoff from rain that falls on hard surfaces such as roads, driveways, and parking lots. Sometimes referred to as a green gardens, these structures are located in depressions filled in with soil, mulch, and vegetation and positioned near large impervious surfaces, as seen in Figure 5 below (Voskamp & Van de Ven, 2015; S. Zhang & Guo, 2012). In Copenhagen, a rain garden must be located 5 m away from the foundation of residential building (L. Nygaard Arre, personal communication, March 15, 2016).

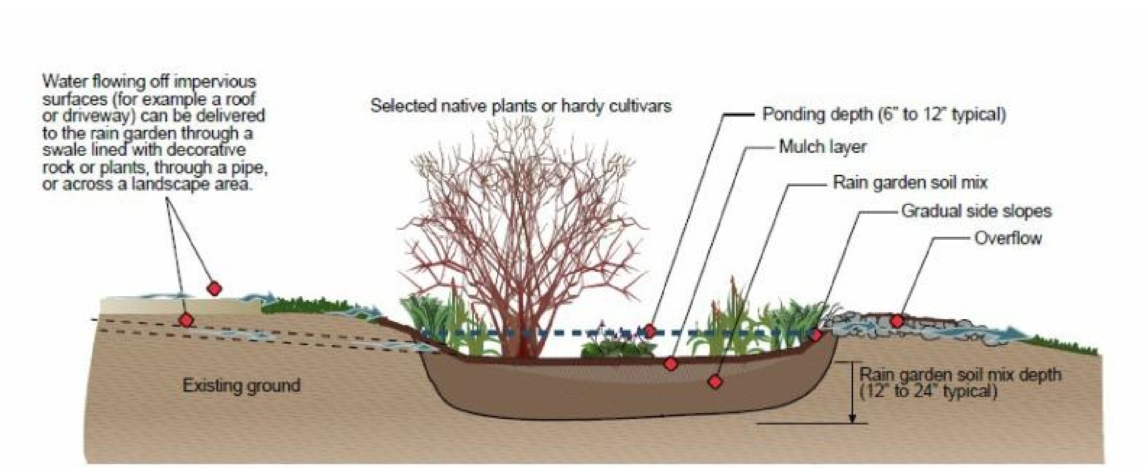

Figure 5: Design of a rain garden (City of Gallatin, 2015).

Like green roofs, rain gardens depend on local conditions and other parameters that should be addressed in their designs. In Corinth, Greece, Papafotiou and Katsifarakis (2015) evaluated local conditions to determine whether rain gardens were feasible for managing rainwater at certain sites using the following criteria: “a) rain garden efficiency, b) upgrading of degraded sites and c) minimization of additional cost (e.g. asphalt pavement removal)” (p. 385). Papafotiou and Katsifarakis (2015) also determined the importance of the area’s elevation compared to sea level when considering rain gardens to ensure that the excess groundwater would leave the site, an important consideration given Amager’s low elevation. In order to determine rain garden effectiveness, S. Zhang and Guo (2012) developed an equation and tested it against existing data from rain gardens in Atlanta, Georgia and Flagstaff, Arizona. They took into account several variables such as surface depression depth, soil properties, soil depth, and local climate. Similar to the catchment efficiency applied to green roofs, the capture efficiency is the ratio between the average amount of water sequestered and the average amount the rain garden has been exposed to per year. The authors found that the capture efficiency was improved with lower humidity, larger surface depression depth, the use of underdrains to help prevent ponding and promote groundwater recharging, and increased absorbency of the soil or mulch used to fill the garden resulting from higher sand content. In addition to reducing runoff, rain gardens have also been shown to filter pollutants from cars and other sources (S. Zhang & Guo, 2012). Rain gardens can therefore be used for filtering water from both roofs and hard surfaces on the ground. A summary of green roof and rain garden functions and factors impacting the effectiveness of each strategy is displayed below in Table 2.

Table 2: Summary of green roof and rain garden functions and variables that influence their effectiveness (Lee et al., 2013; Voskamp & Van de Ven, 2015; S. Zhang & Guo, 2012).

	Green roofs	Rain Gardens
Functions	Storage, attenuation	Attenuation, infiltration
Runoff mitigation measurement	Catchment efficiency (runoff/total rain)	Capture efficiency (rain captured/total rain)
Geographic and climate parameters	Rainfall, rate, amount, and duration per event, rainfall event frequency, evaporation rate	Rainfall, rate, amount, and duration per event, rainfall event frequency, elevation, terrain slope, humidity, evaporation rate
Other variables	Plant types, substrate components, roof slope, green roof depth	Plant types, soil component amounts, surface depression depth

Another related blue-green technique is the bioswale. These structures collect and filter water from a specified area using a surface depression filled with vegetation (Soil Society of America, 2016). Bioswales are typically deeper than rain gardens, are more linear, and require specific designs and materials (Soil Society of America, 2016). According to the National Association of City Transportation Officials, the bottom of the bioswale's trench must be 1.5 m from the water table and the soil used in a bioswale should have at most 5% clay content (National Association of City Transportation Officials, 2016). They are often included near streets and other areas with cars as they are able to filter out pollutants when it rains (see Figure 6). In addition, bioswales help the water infiltrate into the groundwater instead of collecting on hard surfaces and dissolving more pollutants. This also slows down the rate at which the rain flows off the pavement, decreasing the risk for erosion (National Association of City Transportation Officials, 2016). Bioswales therefore present a solution similar to rain gardens that can be used to reduce runoff from nearby impervious surfaces.

Figure 6: A bioswale next to a road (National Association of City Transportation Officials, 2016).

Another strategy that can be applied on the small-scale is the stormwater planter. Stormwater planters are similar to rain gardens but are often smaller and can store more water. They can be installed next to homes and connected to gutter systems to capture and use the runoff to water plants (Cahill, Godwin, & Sowles, 2011). The stormwater planter is a type of bioretention system, meaning it uses soil subtrate materials, such as mulch, along with plants to trap pollutants and break them down before releasing the water (Charles River Watershed Association, 2008). For example, stormwater planters were shown to decrease the amount of phosphorus, sediment, and bacteria in the Charles River watershed in eastern Massachusetts (Charles River Watershed Association, 2008). There are two types of stormwater planters: infiltration planters and filtration (flow-through) planters, as seen in Figure 7 below. Inflitration planters allow rainwater runoff to seep back into the groundwater following filtration, much like a rain garden or bioswale. Filtration planters release water through a pipe connected to a typical drain system (Cahill et al., 2011). They are also manageable to install, making them good candidates for indiviudal climate adaptation.

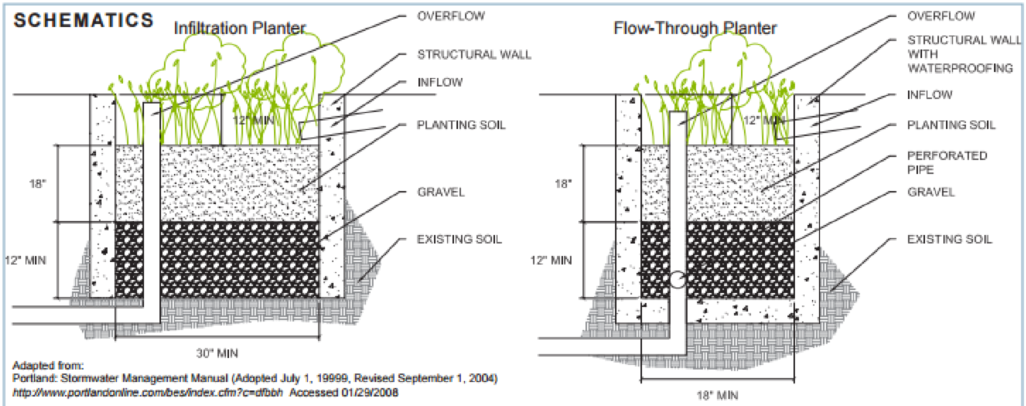

Figure 7: Diagrams of infiltration and filtration (flow-through) planters (Charles River Watershed Association, 2008).

Other small-scale green elements include planters and flower beds. Common planters include traditional planter boxes that contain soil for growing plants. Moveable planters contain wheels that allow them to be used for growing sensitive food crops that must be moved inside during colder months, or located in spaces that must remain flexible. Self-watering planters retain additional water in an open area under the soil. Water added to this cavity will be absorbed by the soil as it dries out; this capilary action also can filter out pollutants from roof runoff or other sources that may have entered the water (TagTomat, 2013). A similar strategy that is instead open to the soil underneath is a raised flower bed. These enclosed areas of soil and vegetation are structured like planter boxes, but without the bottom that would prevent water from flowing directly into the ground. Finally, traditional flower beds, garden areas of soil and plants at ground level, also have the potential to retain rainwater and increase the aesthetic appeal of an outdoor area.

Green spaces also have positive effects related to runoff and pollution in urban areas. These spaces, such as "parks, street trees, urban agriculture, residential lawns and roof gardens" (Kabisch & Haase, 2014) have been shown in many to studies to benefit the environment by increasing water infiltration and purification, decreasing urban noise pollution, and filtering and cooling air, which reduces the urban heat island effect (Kabisch & Haase, 2014). Urban green spaces also improve the mental and physical health of residents by reducing stress and providing areas for physical activity (Kabisch & Haase, 2014). In Copenhagen, the various green spaces throughout the city have a cooling effect, which in turn helps lower the surface temperature of the city (The City of Copenhagen, 2011). For areas with hard surfaces that bear weight, grass grids can be effectively used to incorporate green space. The grass grows through plastic grids, allowing for the addition of green space without compromising the functionality of the area. For example, a grass grid product from Danish company NetByggemarked can hold 160 tons per square meter (NetByggemarked, 2016). These benefits support the use of green spaces in place of hard surfaces on private property.

An important social co-benefit of green spaces is the opportunity for community bonding through shared gardening and other activities. According to volunteer Jann Kuusisaari, UrbanPlanten provides planters and other spaces that people in the neighborhood can use. In addition to teaching people about growing food and environmental appreciation, the center allows the community to garden and build projects together (J. Kuusisaari, personal communication, March 16, 2016). Another project in Copenhagen, the Climate Resilient Neighborhood in Østerbro, is designed to help manage rainwater with green strategies such as green spaces and specially designed roads. One area that was completed in December of 2014 is Tåsinge Plads, a climate-adapted park. It serves as a meeting place for the community while providing a space to help reduce runoff in the urban area (S. Paluszewski-Hau, personal communication, March 17, 2016). These activities combine green methods to manage rainwater with effective use of the water for gardening.

Storage of roof runoff in rain barrels and cisterns is an easy way to reduce the amount of stormwater runoff, as well as harvest water for reuse. While this technique is typically recommended for areas that experience dry spells in between rain events, it can still be effective in areas with frequent rain, such as Copenhagen, as a means of reducing surface runoff rate and amount (Guo & Baetz, 2007). Water stored using this method typically contains a large number of pollutants picked up from roofs. Because of this, the water is considered non-potable, meaning it is not safe for consumption or directly watering food crops. The water can still be used for washing hard surfaces like walkways and the sides of buildings or for irrigating green spaces. If the runoff is directed through other forms of green infrastructure before being used, such as self-watering flower beds, some pollutants will be naturally filtered out, which makes the water more usable.

While small-scale blue-green rainwater management strategies can be implemented independently, they can become even more effective when combined into one system. According to Voskamp and Van de Ven (2015), the combination of several blue-green solutions increases the effectiveness and resilience of green rainwater management; in other words, multiple elements can synergistically reduce runoff and filter pollutants, even in extreme weather situations. Some cities around the world have used one or more of these solutions to attempt to convert typical water management into blue-green solutions, instead of simply removing the water from the affected areas. Figure 8 below summarizes some examples of green rainwater management with elements applicable to Amager.

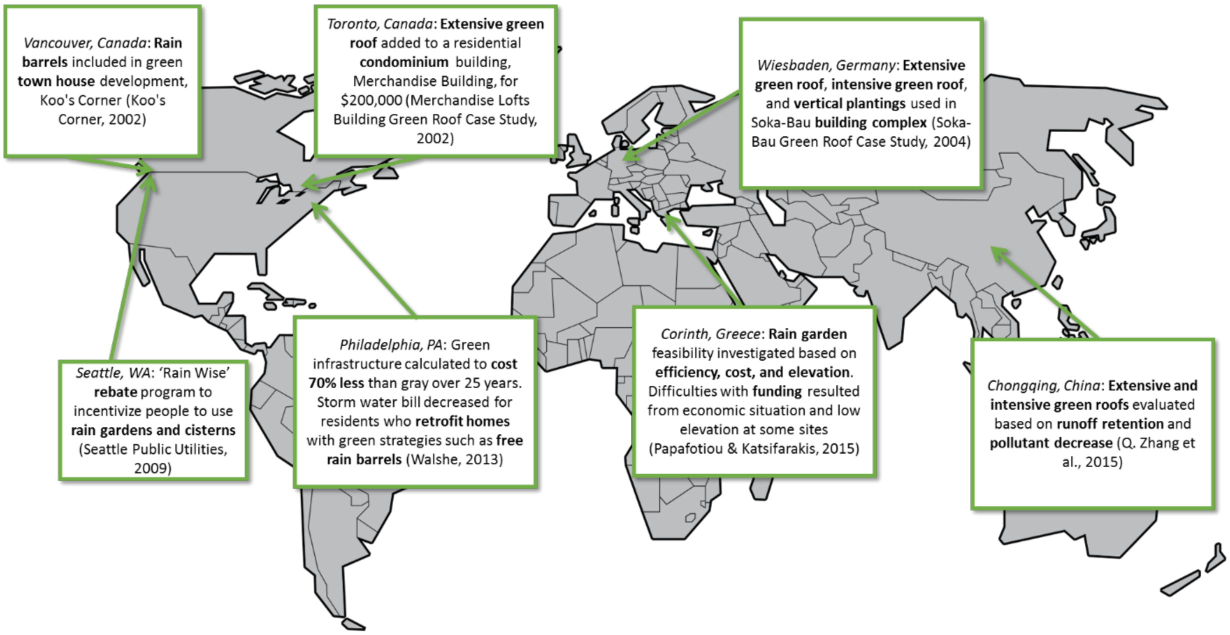

Figure 8: Example of green rainwater management around the world (Koo's Corner, 2002; Merchandise Lofts Building Green Roof Case Study, 2002; Papafotiou & Katsifarakis, 2015; Seattle Public Utilities, 2009; Soka-Bau Green Roof Case Study, 2004; Walshe, 2013; Q. Zhang et al., 2015).

In order for these green solutions to be implemented on a smaller scale, residents must actively participate so that their collective efforts can improve rainwater management in a particular area. A way to encourage individuals to take part in any social movement is through the utilization of human capital. Two forms of human capital that are most relevant to green rainwater management in Copenhagen are social and cultural capital. Social capital is skills and knowledge that individuals bring to a social interaction; cultural capital is the formation of a societal standard through education that over time almost all residents take part in, and if they do not, they are considered out of place (Bourdieu, 1986; Green, Shuster, Rhea, Garmestani, & Thurston, 2012). A goal of green initiatives is to invest in social capital (i.e. neighbors encouraging each other to install rain gardens) to cause an increase in cultural capital (i.e. the expectation to recycle resources). The benefit of these human capitals is that the generation following these changes will be predisposed to follow the social patterns that they witness, making them more likely to install green measures in their own residences. For this reason it is important that the community members are heavily involved in the solutions we recommend. According to Susanne Paluszewski-Hau, an employee of the Amager Øst Local Committee who has worked on urban green space projects, when recommending modifications and solutions it is important to consider how the space is currently being used and to adapt the solutions in a way that they will complement its use; this will also give the community members a sense of ownership (S. Paluszewski-Hau, personal communication, March 17, 2016). Allowing community members to have this input increases interest, involvement, and social capital.

The Area of Amager

Amager is a Danish island in the Øresund Strait. Two northern districts, Amager Øst (estimated population of 55,205 in 2015) and Amager Vest (estimated population of 64,967 in 2015), are part of the capital city Copenhagen (City Population, 2015). The island of Amager is extremely flat with a typical elevation of 3 m above sea level (Flood Map, 2014). As a result, continuous rain and flooding represent a large problem for the area and create a need for renovated rainwater management solutions. Due to the reasons stated in previous sections and Amager being a largely residential area, new methods of rainwater management will include small-scale climate adaptation strategies implemented by residents on their own property.

Amager has changed drastically from the agricultural region it was hundreds of years ago to the urban area it is now. As such, there is a large variety in the types of buildings and architecture in the area, including old cottage homes, new villas, twentieth century apartment complexes (see Figure 9), and modern housing complexes built in the past decade (Visit Copenhagen, 2016). Each of these types of residential structures will require different green rainwater management solutions. Due to time constraints, we will focus on a specific apartment complex chosen by Miljøpunkt Amager for in-depth analysis and specific design of solutions, while also proposing possible solutions for other building types. Other human factors also influence which solutions are feasible. For example, the economic status of the property owner will limit which options they are willing to use since they will ultimately be responsible for paying for the system. Since Amager is expected to be fairly diverse in age, education, and economic status, it is important to understand which groups of people are willing to commit to climate adaptation and why others are not so that we can make it possible for everyone to participate.

Figure 9: An example of a housing complex in Amager Vest.

Summary

Environmental challenges have worsened as a result of global climate change. In Denmark, the most damaging of these issues are the frequent rain and flood patterns that have developed due to extreme rainfall, especially in Copenhagen. Since current methods of managing rain are predominantly gray and can be ineffective, green solutions implemented by individual residents of Amager are needed to reduce runoff and pollution to further protect the environment.

Methods

This project was designed to determine possible cost-effective green rainwater management solutions to be implemented by residents in Amager. We researched possible solutions that would reduce rainwater runoff in the districts of Amager Øst and Amager Vest. Our sponsor, Miljøpunkt Amager, works within the community to inform and empower residents to take part in environmental protection and sustainability (Miljøpunkt Amager, 2016b). Our objectives for this project were to:

1. Evaluate green rainwater management techniques to recommend to Amager citizens
2. Collaborate with a model community to design a green rainwater management plan
3. Determine community members' attitudes toward green rainwater management strategies
4. Create informational webpages to encourage residents to implement green rainwater management strategies in Amager

The remainder of this chapter is dedicated to detailing the methods that were used to accomplish each objective.

Objective 1: Evaluate green rainwater management techniques to recommend to Amager citizens

When selecting any product or strategy, it is essential to understand and evaluate all options available to make an informed decision. In order for us to recommend strategies, we reviewed literature on green rainwater management techniques. From the strategies reviewed, those that can be easily installed by a property owner were selected, further researched, and compiled into a preliminary matrix (Appendix A). To evaluate each strategy, we quantified them based on the metrics of water retention and cost. This allowed us to compare each rainwater management strategy more precisely and provide better recommendations. Retention percentages were gathered from different literature sources either directly as retention or by calculating the retention based on the catchment efficiency. Since the catchment efficiency is the ratio of runoff volume to total volume, the retention is equal to one minus the catchment efficiency. Costs were estimated based on the price of materials and do not include labor or other possible modifications to the site.

Furthermore, investigation of the buildings in Amager was conducted to determine how they could be adapted to green rainwater use. Since there is a variety of building structures and property spaces in Amager, we had to ensure that any recommendations we made could be employed safely in the applicable areas. To better inform ourselves about building types, we completed unstructured interviews with the employees of Miljøpunkt Amager and people with experience constructing green roofs to get a sense of the structural and architectural requirements for possible solutions. We discussed with them the different building types and what techniques for water management were already being used in Amager. This information was stored in a document that only group members had access to, and was analyzed to determine which green rainwater management solutions would best be adapted to existing structures.

Finally, we collected data on the types of buildings comprising the neighborhoods of Amager through visual observation. We convenience sampled buildings from Amager Øst and Amager Vest using

Amagerbrogade as a dividing line between the areas (see Figure 10). We also captured our observations for each building we sampled with photographs to provide us with a visual representation of the complexity of the area of Amager, and the different challenges that citizens could encounter when trying to install a blue-green solution. The address, GPS location, and names of residents were not recorded or displayed in final images.

Figure 10: Map of Amager with Amager Øst (orange) and Amager Vest (red) labeled.

Objective 2: Collaborate with a model community to design a green rainwater management plan

After we evaluated a list of green rainwater management techniques and determined the community members' attitudes and criteria for potential strategies, we worked with a model community to design an effective, context-specific green strategy. Miljøpunkt Amager identified an apartment complex for us to work with for this component of the project. This community has 172 individually owned flats and a committee for courtyard maintenance and improvement (A. B. Petersen, personal communication, March 21, 2016). The committee expressed interest in improving not only their water management in a green way, but also increasing the community's interactions with urban gardening. In addition, they were interested in designs that would require volunteer work to bring community members together to build the new aspects of the courtyard, increasing the community investment in the space.

This collaborative design process involved a three step strategy. First, we evaluated the interests of the committee members for the design based on unstructured interviews with two committee members of the courtyard for the apartment complex, Anders Bo Peterson and Andreas Zacho. Once we evaluated the feasibility of incorporating the community gardens and increased green space into the new courtyard, we designed a visual using Revit, a 3D architectural modeling software. After creating the design, we presented it, along with the estimated cost for each solution and their water retention values, to Peterson and Zacho, who shared it with the courtyard committee members. Once they reviewed the proposed design, we were able to determine what aspects they liked, what elements they thought should change, and what additions they wanted to see. After receiving feedback, we reevaluated and modified the design, introducing two revised designs and table of additional options culminating in a final design. These design options will be used to propose changes to the housing board at a later date. Figure 11 below is a graphic representation of the process described above.

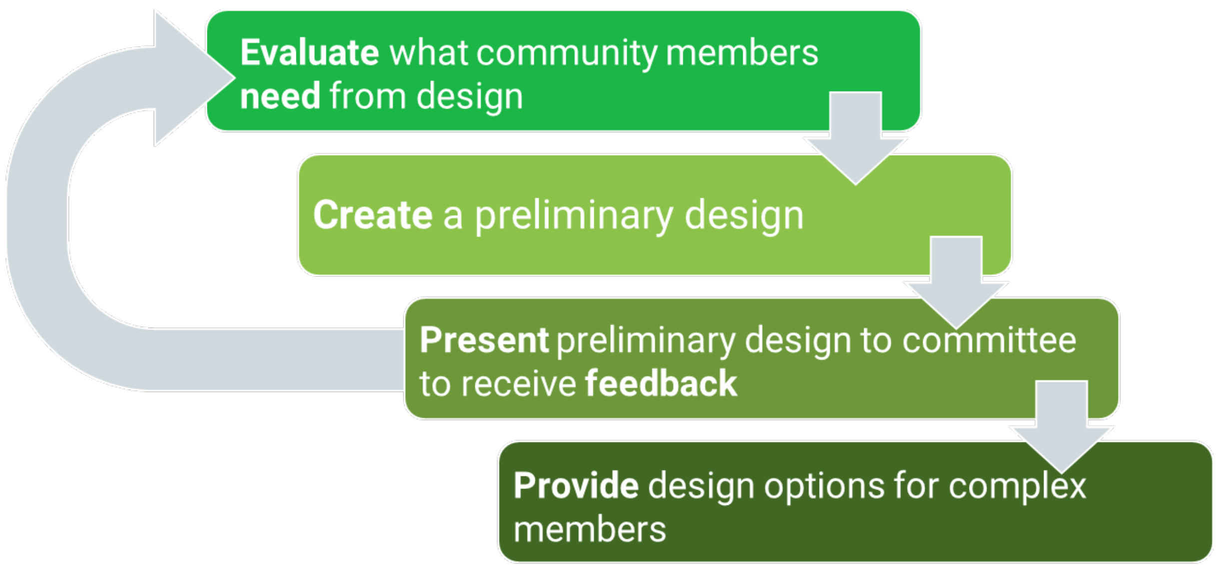

Figure 11: Diagram depicting the collaborative process that was used to design the green rainwater management plan for the courtyard.

When proposing our designs to Peterson and Zacho, we calculated the cost and retention of each strategy. To do this, we used the percent retention values that we gathered from our literature review, which are summarized in Table 3 below; for strategies that did not have retention values for the intensity of a 10-year rain event, or if the retention is a range, we estimated the percentage by taking the average of the range. The retention percentage was then multiplied by the surface area of the strategy and the depth of rainfall (50 mm for a 10-year rain event), resulting in the volume of rainwater retained by that strategy. The retention volumes only represent the amount of rain that falls directly onto the area and do not take into account runoff from nearby impervious surfaces.

Table 3: The retention percentages of green strategies for a 10-year rain event (Lee et al., 2013; Mechell & Lesikar; S. Tang, 2016; Technology, 2016; B. Zhang, Xie, Li, & Wang, 2015).

Strategy	Retention Percentage	Source
Rain Garden	94%	(Tang, Jia, Liu, Li, & Wu, 2016)
Green Space	77%	(Zhang, Xie, Li, & Wang, 2015)
Grass Grid	75%	(Zhang, Xie, Li, & Wang, 2015)
Flower Bed	65%	(Mechell & Lesikar)
Raised Bed	65%	(Mechell & Lesikar)
Green Roof	53%	(Lee, Moon, Kim, Kim, & Han, 2013)
Gravel	50%	(Setford Consulting & Technology, 2016)

The cost of each strategy was calculated based on the cost of materials. For strategies like rain gardens, green spaces, and flower beds the cost was calculated per square meter and then multiplied by the area for the total cost. For strategies like planters and rain barrels the cost was calculated per unit and then multiplied by the number of units. The costs were estimated based on only the materials necessary for construction and do not include other modifications to the courtyard or labor to implement the strategies.

Objective 3: Determine community members' attitudes toward green rainwater management strategies

We investigated which solutions are technically feasible for individuals in Amager, and the community members' views of green rainwater management to determine how open they were to adding green elements themselves. Since individuals must actively participate in order for possible green solutions to be added on a small scale, the attitudes of the residents are a great factor for our recommendations.

First, we conducted unstructured interviews with Miljøpunkt Amager employees and others involved in environmental outreach to learn about their view of community members' involvement in climate adaptation efforts. As an organization that reaches out to the community for ideas and gives back through sustainability programs, they have observed firsthand how residents have or have not expressed interest in green solutions in general and those related to rainwater management. This helped us visualize what social and cultural capital already existed with regard to sustainability and green rainwater management that we could access to better understand the community interactions. These interviews provided us with a baseline and general understanding of the community's collective impression of climate adaptation efforts.

To further investigate the opinions of community members on green solutions, we conducted an online survey. We sent the survey to subscribers of Miljøpunkt Amager's monthly newsletter. This survey contained questions about demographics: age, occupation, and housing ownership. Since age may impact an individual's ability or willingness to install a green rainwater management solution, we believed it was an important parameter to consider. In addition, occupation allowed us to estimate economic status, which likely factors into the respondents' opinions regarding green solutions and their cost, as was seen through the difficulties financing rain gardens in Greece (Papafotiou & Katsifarakis, 2015). Another important variable is whether the resident rents or owns their living space. According to Voskamp and Van de Ven (2015), ownership of the land on which the residence is located greatly influences whether blue-green solutions are used. The researchers observed that it is more challenging for solutions to be added in privately-owned areas due to cost and the perception that the city will benefit more than the property owner from the additions (Voskamp & Van de Ven, 2015).

Our next questions focused on what people know about green solutions in general, their opinions of them, and their familiarity with different green elements. We also asked about the respondents' experiences with household flooding. In addition, we ascertained factors that might be considered when selecting a green solution to implement, such as cost and functionality. For survey questions and the introductory preamble for informed consent, see Appendix B. We saved answers in a folder that did not contain names and was only accessible by group members and our sponsor.

Objective 4: Create an informational web page to encourage residents to implement green rainwater management strategies in Amager

An additional objective of this project was to raise awareness of climate adaptation methods that residents can implement independently. According to our Miljøpunkt Amager contact Lise Nygaard Arre, in order to mitigate the effects of climate change, Copenhagen is attempting to increase the amount of citizens actively participating in climate adaptation to 30% (L. Nygaard Arre, personal communication, February 8, 2016). To help reach this goal, we created two webpages on Miljøpunkt Amager's website with information about the benefits of green rainwater solutions over their gray counterparts, as well as examples of these green solutions that residents can implement themselves and the final courtyard design.

We met Nygaard Arre, the employee responsible for updating the website, to better understand the formatting they would like us to use and any constraints on length or size. We used the information from the online survey to understand what residents already know about green solutions and what they would like to learn. Our findings from our work with the model community also gave us a strong understanding of green rainwater management solutions that could be applied to many similar buildings in Amager. By compiling the information we gathered from the literature review, interviews, survey, and model community, we developed two webpages. The first contains an infographic summarizing the functions, costs, and water retention percentages of each strategy; details about each strategy, including structural requirements and images; and an introduction to the courtyard design. The second webpage, which is linked to the first webpage, contains details of the final courtyard design, including visuals, explanations of how each strategy was incorporated, and water retention and cost values. We confirmed with Nygaard Arre that the information we intend to provide correlated with what she had hoped to achieve through the webpages. The final versions of the webpages and the infographic were translated to Danish with help from Nygaard Arre. We incorporated many visuals and clear, concise descriptions in order to convey the information clearly and easily to the residents of Amager or others who may view the pages.

Schedule

Below in Table 4 we have outlined the timeline for the tasks we completed as part of our methods in order to accomplish our objectives.

Table 4: Gantt chart showing our schedule of tasks based on our methods and objectives.

Objective	Task	Week 1 (3/13)	2 (3/20)	3 (3/27)	4 (4/3)	5 (4/10)	6 (4/17)	7 (4/24)	8 (5/1)
1	Interview MPA Employees	■							
	Interview Experts	■	■	■	■	■			
	Observe Neighborhoods		■						
2	Interview Courtyard Committee		■						
	Design Prototype			■	■	■	■	■	
	Present to Courtyard Committee				■	■	■	■	
3	Process Expert Interviews			■	■	■	■		
	Newsletter Survey				■	■	■		
	Process Newsletter Surveys						■		
4	Webpage						■	■	
	Translate and format webpage							■	
	Final Presentation								■

Results

Our deliverables for this project were a green rainwater management plan that we developed for the courtyard of a housing complex in Islands Brygge and two informational webpages detailing green solutions. Our recommendations for the employment of green rainwater management solutions by the complex assisted by Miljøpunkt Amager are detailed in this chapter. In addition, we developed two webpages, explained later in this chapter, to publicize the information that we gathered throughout our work and empower the citizens of Amager to add in their own rainwater management solutions on their properties.

Courtyard Design

To model the applicability of green rainwater management solutions within housing complexes and their courtyards, we worked with Anders Bo Peterson and Andreas Zacho, two members of the housing complex's courtyard committee, to create a design for their courtyard. We visited the courtyard to discuss our ideas, the committee's thoughts, and the community's desires with Peterson and Zacho.

The main courtyard area is 115 m long and 14 m wide and contains a variety of different areas, as seen in Figure 12; the smaller area near the entrance is 12 m long and 9 m wide. To the left of the entrance, at the far end of the courtyard is a large patio (location 1) with in-ground drains for rainwater management, and several small flower beds. Next to the patio area there is a small wooden shed with a flat roof (location 2), which was modified with the intention of installing a green roof. To the right of the shed is an open area for clotheslines (location 3) with cement tiles and small amounts of grass between them. There is a small patio (location 4) surrounded on three sides by raised flower beds. At the gate entrance to the courtyard there is an area on the left side with a swing set (location 5) and a large sandbox area with a table and chairs on the right side (location 7). In the center of the courtyard there is a long, inclined grass area and deck (location 6). On the opposite side of the grass area, the small patio, clotheslines, and shed are mirrored; however, this shed's roof is peaked instead of flat (locations 8 and 9). On the right side of the shed is a large encaged basketball court with a fence roof (location 10) followed by a patio area with four V-shaped planters (location 11). On the other side of the patio is a large square shed with a pitched roof (location 12). Along the back wall is a dirt area running the entire length (location 13) with seven small trees and some small plants. The wall is only a few meters high and is adjacent to an open parking lot on the other side of the wall, which allows for additional sunlight to enter the courtyard. There are also thirteen downspouts that run directly from the gutters into the ground and are connected to the city's sewer system. The courtyard has already taken some measures to prevent basement flooding by raising the railing around their basement stairs by a few centimeters (Figure 12, asterisked).

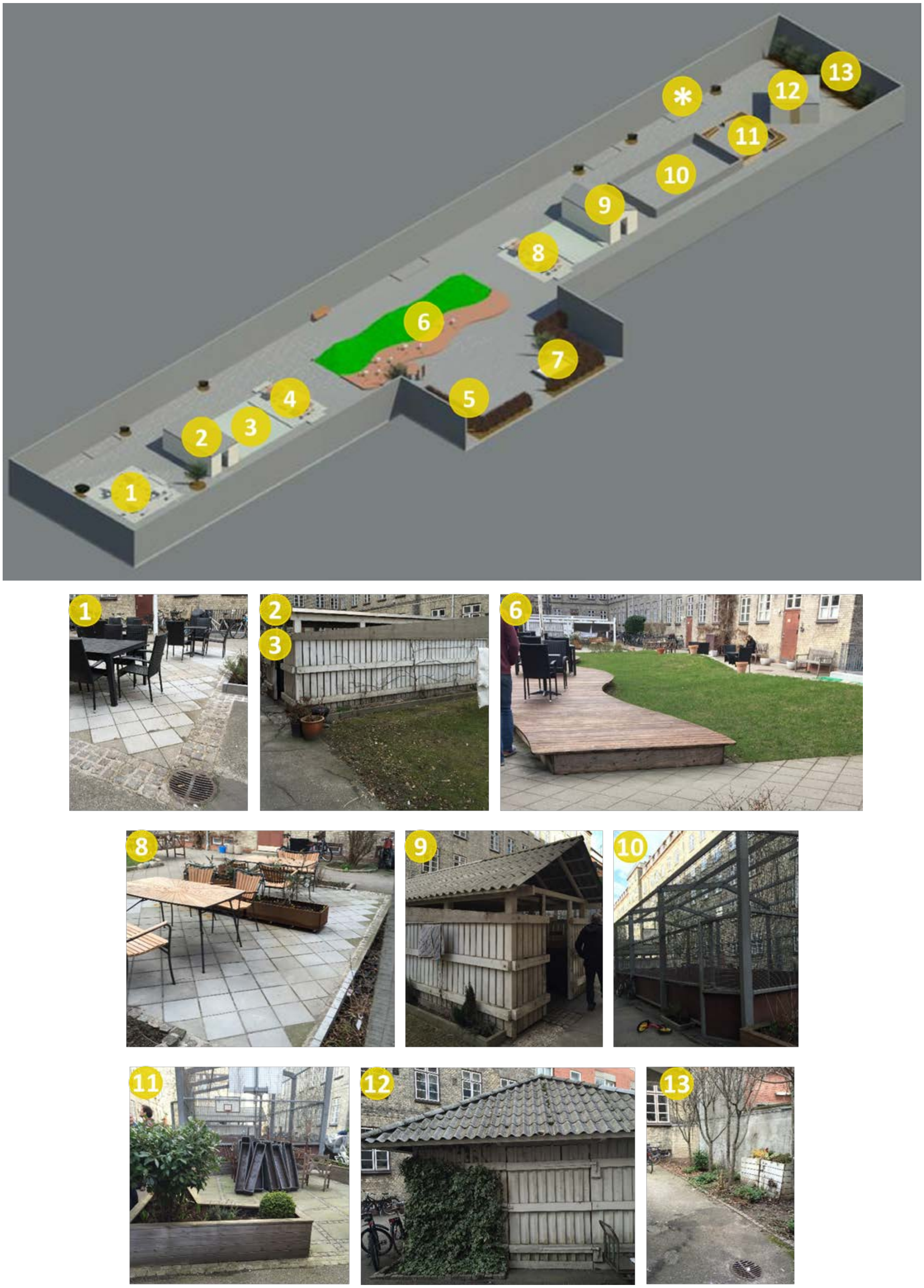

Figure 12: Current Islands Brygge housing complex courtyard layout.

We modeled the current layout of the courtyard in the program Revit based on our observations, measurements, and an original schematic of the space. To determine how well the current courtyard and each design retains water, we calculated that 85,900 L of water falls directly onto the courtyard in a 10-year rain event (50 mm) based on the area of the courtyard (1718 m^2). We determined that the current courtyard retains 5,266 L, or 6.13% of the total rain, given the retention capacity of the existing areas. To compare the designs to the hypothetical maximum retention of the courtyard, we also calculated the percent total retention if one-third of the area were converted into a rain garden and two-thirds into green space to be 71,011 L (82.67 %). This would mean that currently, the courtyard can retain 7.81% of the theoretical maximum volume. Calculations of cost and retention by strategy can be found in Appendix C. From there, we started with several rainwater management strategies to improve this value based on ideas introduced by the courtyard committee and our literature research, as seen in our preliminary design in Figure 13. The committee suggested green roofs on the sheds (locations 2, 9, and 12) since they recently replaced one with a flatter roof and can easily replace the other as well. Jann Kuusisaari, who has been working with Miljøpunkt Amager to inform residents about how to make their own green roofs for their homes, also mentioned during our interview that green roofs are easy to install with ready-made elements or raw materials, so we incorporated them into our courtyard design (J. Kuusisaari, personal communication, March 16, 2016). They also wished to see a community garden area added with moveable planters to continue plant growth in the cold seasons and allow for easier snow removal. The movable planters can retain a fixed amount of rainwater depending on their size while also adding communal and social involvement by allowing residents to have their own personal gardens.

We developed a preliminary green rainwater management plan for the courtyard centered on what we initially discussed with the committee, as seen in Figure 13 below. For example, in the clotheslines areas (location 3) replacing the stone tile with a grass grid would increase the amount of green space in the courtyard. The grass grid allows for the area to support weight without becoming muddy for residents drying their laundry. We also suggested that the walkway areas between the central green space and patios (locations 6 and 4/8) be adapted with gravel, green strips, or grass grids to increase water retention. Nygaard Arre suggested the addition of rain barrels to the gutter downspouts to collect water for later use in the movable planters. When we met with Popowitz, he described that residents can receive compensation for managing rainwater locally by either disconnecting from the main sewer system or doing projects in public common areas (M. Popowitz, personal communication, April 12, 2016). If the rain barrels can collect the water that is falling onto the roof of the building and draining into the sewage system, then the housing complex may be able to disconnect from the sewer system enough to receive a reimbursement from HOFOR. We considered the addition of a rain garden on the edge of the green space (location 6), but they are not applicable in this case. According to the Technical and Environmental Administration, the water table around the housing complex is 1.8 m below the surface, meaning the ground will be saturated with water at 1.8 m, preventing further water infiltration (Technical and Environmental Administration, personal communication, April 14, 2016). Therefore, a rain garden or other strategies that require trenches to direct water into the ground would not be feasible. In total the preliminary design increases the retention of the courtyard by 4,941 L (5.75%) to 10,207 (11.88%) and costs DKK 55,114. Note that cost estimations only include materials.

Figure 13: Preliminary design for Islands Brygge housing complex courtyard.

After presenting our preliminary design, we made some adjustments based on feedback from Peterson and Zacho. They indicated that they would be open to more drastic changes to the courtyard to help reduce runoff and redesign the space, so we created two additional designs, one similar to the preliminary design and another with more drastic changes. The first revised design expanded on the preliminary design with many similar elements alongside additional ones, as seen in Figure 14 below. We added flower beds around the patios at locations 1, 4 and 8 to help retain water from the patios and pavement and add aesthetic appeal to communal areas. For the clotheslines area (location 3), we replaced the grass grid with grass and pavers. This would still add green space and allow people to walk through the area without it becoming muddy, but is less expensive and could be easier to install. After discovering that the adaptation of walkway areas would be impractical based on waste management codes for moving trash receptacles, which require paths with 1.5 m of hard surface, we removed the adaptations to the walkway areas for all designs. We also added homemade moveable planters around the swing set and sandbox in the gate area (locations 5 and 7). Zacho suggested the inclusion of a permanent community herb garden in a central portion of the courtyard, so we incorporated a raised-bed herb garden along the deck of the green space at location 6. We also kept the rain barrels in each design. In total the first revised design increases the retention of the courtyard by 5,523 L (6.42%) to 10,789 (11.88%) and costs DKK 93,348. A summary of the retention and cost values can be seen in Appendix D.

Figure 14: First revised design for Islands Brygge housing complex courtyard.

The second revised design, shown in Figure 15 below, also built off the preliminary design but included larger changes. After learning that the basketball court is not used often by residents, we replaced it with a recreational green space that could be used for relaxation or basic sports activities for children. We also noticed that the gate area received more light during the day than the ends of the courtyard, so we replaced the swing set at location 5 with a larger number of planters than in the first revised design to promote growing vegetables and flowers. To keep the swing set for the young children, we moved it to location 11. In addition, we kept the grass grid in the clotheslines areas from the preliminary design. During our meeting, Peterson and Zacho also mentioned issues with cluttered bike parking within the courtyard, so we designed a planter bench with slats for parking bikes to replace the old shed at location 12; this provided more communal space, bike parking areas, and additional green elements. Finally, we improved the area of soil and trees against the wall on the right side of the courtyard (location 13) by extending the soil 1 m away from the wall and adding vegetation to increase the water retention of the area. In total the second revised design increases the retention of the courtyard by 7,877 L (6.42%) to 13,143 (15.30 %) and costs DKK 106,076. A summary of the retention and cost values can be seen Appendix D. In addition to the two designs, we provided Peterson and Zacho with a table detailing options for each location and their estimated water retention and cost. This provided the committee with metrics for each option included in the revised designs and allows them to choose from additional ideas for the locations. The table can be found in Appendix D.

Figure 15: Second revised design for Islands Brygge housing complex courtyard [12 (Li & Lauritsen, 2016)].

After receiving additional feedback from Zacho, we created our final design, as seen in Figure 16 below. This design is nearly identical to the second revised design, but with the clotheslines area containing grass with pavers instead of the grass grid. In total, this courtyard design retains 13,141 L (15.30%), a 150% increase in retention when compared to the current courtyard, and costs DKK 102,519. This design achieves 18.90% of the hypothetical maximum retention of 71,011 L (82.67% of the total rain that falls on the courtyard). The retention values and cost for each aspect of this design can be seen in Appendix D.

Figure 16: Proposed design for Islands Brygge housing complex courtyard [12 - (Li & Lauritsen, 2016)]

The final design allows the courtyard residents to view a possible plan for the courtyard that has been based on feedback from the courtyard committee. However, the previous designs (Figures 13-15) and table of options (Additional Strategy Options table in Appendix D) allow the design to evolve based on the opinions of the residents, other committee members, and the housing board.

Informational Webpage

To better educate residents of Amager and the rest of Copenhagen about green methods that reduce the amount of rainwater runoff collected by the wastewater system, we created two webpages for the Climate Adaptation section of Miljøpunkt Amager's website. From the building structure observations, survey responses, and interviews with Nygaard Arre, Paluszewski-Hau, and Kuusisaari, we included information that would be useful for residents who wish to learn about using green rainwater management.

Through observation of residential properties in both Amager Øst and Amager Vest, we identified similar structures that could be adapted to particular green rainwater management strategies. In both districts we observed single and multi-family homes that contained sufficient yard space for rain gardens and small sheds or garages ideal for green roofs. However, we focused on structures associated with housing complexes, many of which contained shared spaces. While some of these courtyards contained green space, they could be improved to better manage rainwater and promote community. Green roofs could be added to the prevalent trash and recycling container sheds. Flower beds or planters could be added around patios or other areas where replacement with green space is not feasible. These observations also helped decide that some strategies are not applicable for implementation on the small scale. Due to the pitch and height of the housing complexes' roofs, we determined that large green roofs on the main buildings would not be possible and that only extensive green roofs would be feasible based on weight. After considering the low water table in Amager and strict structural requirements for infiltration using a bioswale, we decided not to recommend them to residents. Due to the limited yard space observed on some properties, we decided the requirement that a rain garden be 5 m away from the foundation of a residential building be included on the webpage (L. Nygaard Arre, personal communication, March 15, 2016).

We investigated the knowledge and opinions of residents through a survey distributed through Miljøpunkt Amager's online newsletter and interviews (see Appendix B). The survey was sent on April 6 and the responses were then analyzed for common themes (see Appendix E). Of the nine survey responses collected, eight indicated the importance and necessity of environmental sustainability. The respondents were also more aware of energy and water conservation as opposed to rainwater management. In terms of factors important when choosing a green alternative, cost was mentioned the most, followed by impact or efficiency, the longevity of the solution, and, finally, aesthetics. While each respondent knew what a green roof was and five specifically mentioned their function in decreasing runoff, six indicated that they would like more information about installation or the structural requirements. In addition, only one respondent said they would be unwilling to install a green roof. On the other hand, four respondents were unfamiliar with rain gardens and three said they would be unwilling to use a rain garden. Several respondents indicated that they did not understand what makes a rain garden different from a typical flower bed and would like to know about the function and efficiency of rain gardens. Finally, four respondents already had rain barrels and not one said they would be unwilling to install one on their property. From these general trends, quotes from the respondents, and interviews with experts, we decided providing explanations of rain gardens was particularly necessary and that the costs and efficiencies of each strategy would be important to encourage people to implement them. However, all respondents did indicate that they are interested in protecting the environment, which suggests that information presented in an easily accessibly format may encourage residents to actively participate in climate adaptation.

Using information from the survey, interviews, and other research, we created two informational webpages. The first contains an infographic summarizing each solution that a homeowner or complex resident could install themselves with its estimated water retention in a 10-year rain event and cost to guide residents in selecting the most applicable solutions for their properties. This graphic, seen below in Figure 17, could prove useful for quick reference by property owners to determine which solutions are reasonable to implement on their property. To supplement this, further descriptions of each strategy and their structural requirements were included beneath the infographic along with pictures.

Figure 17: Green solutions infographic displayed on Miljøpunkt Amager's website.

We also included a separate webpage linked in the first with a summary of the model courtyard design that we created as an example for other housing complexes to follow. We included the current layout of the courtyard with images of each area (Figure 12) along with our final design (Figure 16) to illustrate the changes made to each space. We explained the rationale behind each strategy that was incorporated into the design. Miljøpunkt Amager believes this will encourage residents of Amager and others who view the website who live in housing complexes to take control of their rainwater management using our designs as a springboard for their own. Below in Figure 18 is a screenshot of our Climate Adaptation Strategies for Rainwater Management webpage and Figure 19 is a screenshot of our Example Courtyard Design webpage, which can be viewed in full at http://www.miljopunkt-amager.dk/climate-adaptation and http://www.miljopunkt-amager.dk/courtyard, respectively. Additional pictures of the webpages may be viewed in Appendix F.

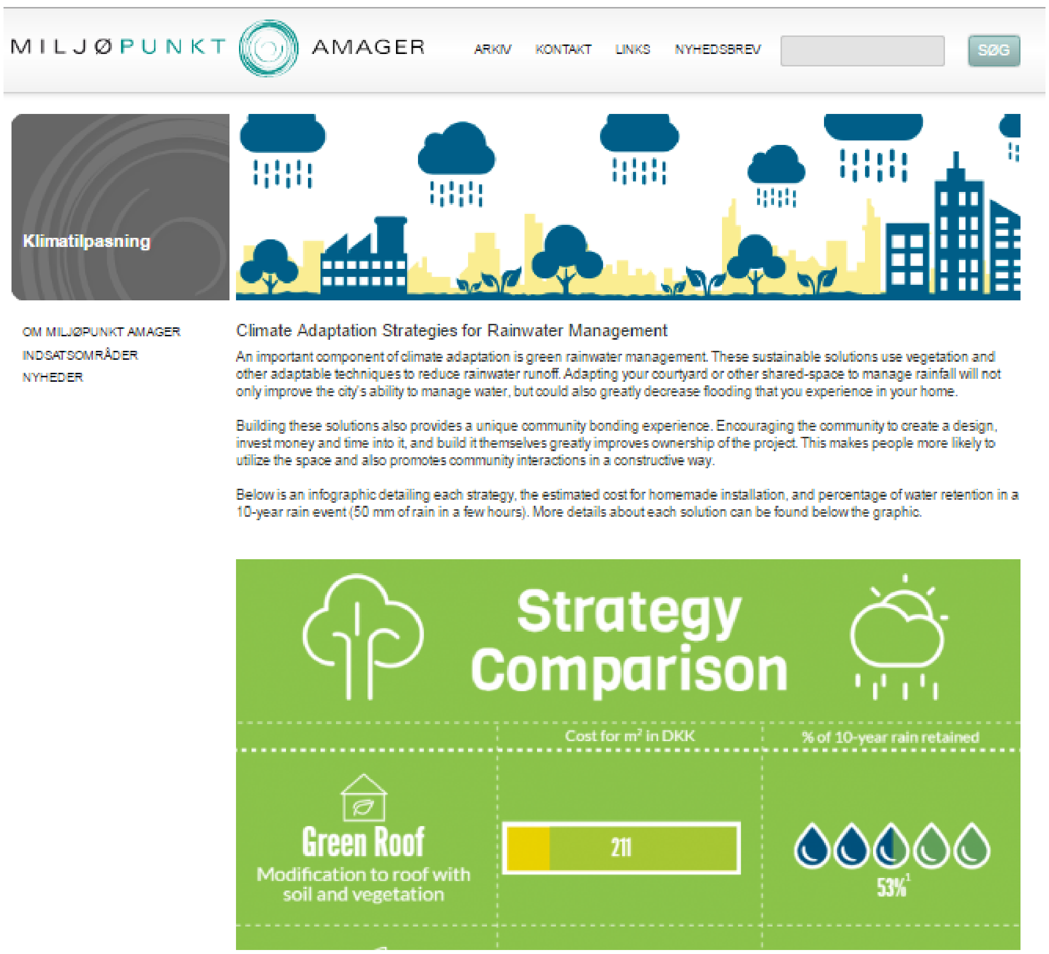

Figure 18: Screenshot of the Climate Adaptation Strategies for Rainwater Management webpage on the Miljøpunkt Amager website.

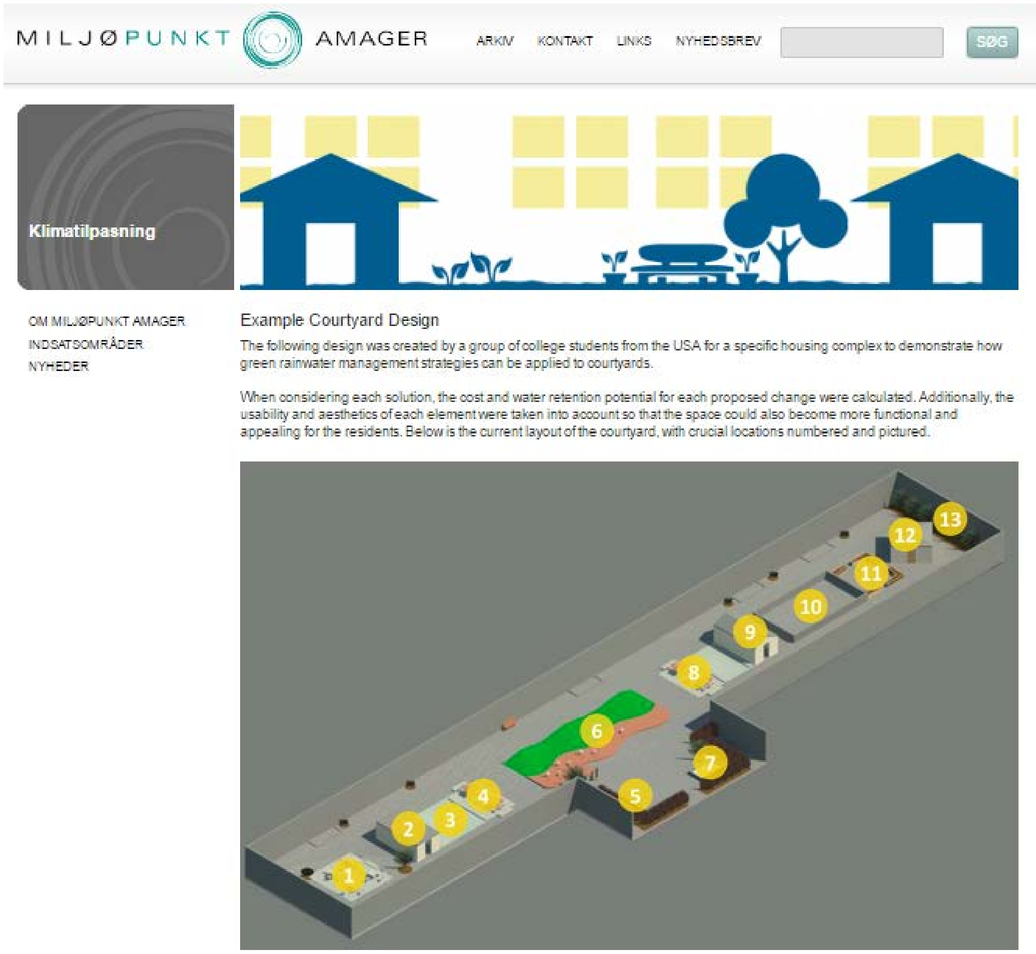

Figure 19: Screenshot of our Example Courtyard Design webpage on the Miljøpunkt Amager website.

Conclusion

While in Denmark, we assessed the viability of various green rainwater management strategies for the Copenhagen districts of Amager Øst and Amager Vest, designed a climate adaptation plan for a housing complex's courtyard in Islands Brygge, gauged the Amager community's interest in utilizing these solutions, and constructed two webpages on Miljøpunkt Amager's website to inform residents about green rainwater management. Throughout this process, the importance of not only managing the rainwater but bringing the community together was frequently emphasized. When a community improves upon the usability of their shared area with their own green rainwater management plan, the residents are more likely to become invested in their designs, maintaining and improving upon them as needed. Green rainwater management also has strong environmental benefits. The decrease in rainwater runoff from individual residences to the wastewater system not only benefits the homeowner, but also decreases pressure on the system itself. The sewage plant currently has to release untreated water into the harbor when the treatment facility is too taxed from rain. By installing these green, small-scale solutions, the community reduces the strain on the water treatment facilities, decreases runoff and the potential for flooding, helps the environment, and gains increased urban green space with potential co-benefits such as pollutant filtration, decrease in the urban heat island effect, and increased community interaction.

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Appendix

Appendix A: Preliminary Green Solutions Matrix

This matrix includes the cost values, ranges for percent runoff decrease, the estimated volume retained in a 10-year rain event, and the benefits of each strategy initially researched.

Green Solution	Cost DKK	% Runoff Decrease	10-Year Rain Retained L/m^2	Additional Functionality & Co-Benefits
Extensive Green Roof	211.07 homemade; 250 premade	65-85% (before reaches capacity)	26.5	cooling of house, reduction in urban heat island
Intensive Green Roof	4872.68	27-81%	27	urban agriculture, recreational space, cooling of building, reduciton in urban heat island
Rain Garden (1x1x.6 m)	1128.28	67.9-99.2%	47	groundwater infiltration
Bioswale	4008.17	88.8% (varies based on dimensions, depth, etc)	44	groundwater infiltration
Planters	1009.10 homemade; 2468.95 premade	N/A	N/A	groundwater infiltration, urban agriculture
Flower Beds (1 m^2)	854.25	40-90%	32.5	aesthetics, urban agriculture
Green Spaces (1 m^2)	23.2	66-77%	36	groundwater infiltration
Rainwater Storage Containers (350 L)	1483.95	N/A	N/A	watering gardens, cleaning buildings
Grass Grid (m^2)	125.79	66-77%	36	groundwater infiltration

Appendix B: Online Survey of Miljøpunkt Amager Newsletter Subscribers

This appendix contains the questions and explanatory text from the online survey sent through Miljøpunkt Amager's monthly newsletter.

Preamble

We are a group of students from Worcester Polytechnic Institute in Massachusetts. We are conducting a study evaluating environmentally friendly rainwater management strategies that property owners of Amager can implement. We believe this kind of research will ultimately enhance the sustainability of Amager. Your participation in this survey is completely voluntary and you may withdraw at any time. Please remember that your answers will remain confidential. No names or identifying information will appear on the questionnaires or in any of the project reports or publications. This is a collaborative project between Miljøpunkt Amager and WPI, and your participation is greatly appreciated. If interested, a copy of our results can be provided at the conclusion of the study.

Questions

Demographics

1. Please select your age range
    a. 18-24
    b. 25-55
    c. 56+
2. What is your occupation?
3. Do you rent or own your living space?
4. What type of space is it?
    a. House (single, multifamily)
    b. Apartment (condo, flat, etc)
    c. Other

Green Alternatives

5. What are your opinions of environmental sustainability? Please describe below any opinions, ideas, or words that you think of.
6. What green alternatives do you know of that you could implement at home?
7. List factors that would be important when choosing a green solution for your home. Please list in the area below anything you would take into consideration if you were to select any type of green solution for your home.

Rainwater Management

8. What problems have you experienced from flooding? Please describe in the space provided below.
9. What methods do you know of for managing rainwater on your property? Please list any methods that you know of that are used to store, divert, or drain rainwater.

Green Rainwater Solutions

The following sections will ask you questions about three different green rainwater management solutions.

10. Green Roofs
    a. What do you know about green roofs?
    b. What more would you like to know about green roofs?
    c. Would you be willing to install a green roof on your property?
        i. Yes
        ii. No
        iii. Other
    d. Why or who not? If you selected yes, please describe why you would like to install a green roof. If you selected no, please describe why you would NOT like to install a green roof.
11. Rain Gardens
    a. What do you know about rain gardens?
    b. What more would you like to know about rain gardens?
    c. Would you be willing to install a rain garden on your property?
        i. Yes
        ii. No
        iii. Other
    d. Why or who not? If you selected yes, please describe why you would like to install a rain garden. If you selected no, please describe why you would NOT like to install a rain garden.
12. Rain Barrels and Storage
    a. What do you know about rain barrels and other storage techniques?
    b. What more would you like to know about rain barrels and other storage techniques?
    c. Would you be willing to install a rain barrel or other storage technique on your property?
        i. Yes
        ii. No
        iii. Other
    d. Why or why not? If you selected yes, please describe why you would like to install a rain garden. If you selected no, please describe why you would NOT like to install a rain garden.

Thank you for your response! If you would like a copy of your results or have any questions, please email our group at amagerclimate@wpi.edu or drop by the Miljopunkt Amager office.

Appendix C: Courtyard Calculations

This appendix contains tables showing the calculations performed to determine the retention values for the current courtyard and the cost and retention values for each design.

Current Courtyard: Retentions

Scattered Trees (5)		
Area (m^2)	2	
Retention %	0.65	
Volume retained (m^3, L)	0.325	325

Back Wall		
Area (m^2)	28	
Retention %	0.65	
Volume retained (m^3, L)	0.91	910

Scattered Beds (12)		
Area (m^2)	1.54	
Retention %	0.65	
Volume retained (m^3, L)	0.601	601

Central Green Space		
Area (m^2)	70	
Retention %	0.72	
Volume retained (m^3, L)	2.52	2520

Large Bushes by Entrance		
Area (m^2)	28	
Retention %	0.65	
Volume retained (m^3, L)	0.91	910

Preliminary Design: Retentions and Costs

Green Roofs				
	Cost/m2 211.7	Retention % 0.53		Totals
Location	2	9	12	
Area (m^2)	20.5	20.5	18.85	**59.85**
Retention (L)	543.25	543.25	499.525	**1586.025**
Cost (DKK)	4339.85	4339.85	3990.545	**12670.245**

Grass Grid			
	Cost/m2 125.79	Retention % 0.72	
Location	3		Totals
Area (m^2)	48.4	28.4	**76.8**
Retention (L)	1742.4	1022.4	**2764.8**
Cost (DKK)	6088.236	3572.436	**9660.672**

Planters		
	Cost/planter 1009.1	Totals
Location	11 (30 planters)	
Area (m^2)	7.191	**7.191**
Retention (L)	359.55	**359.55**
Capacity (L)	2732.58	**2732.58**
Cost (DKK)	30273	**30273**

Walkways							
	Grass grid		Grass Strip		Gravel		Totals
	Cost/m2 120	Retention % 0.72	Cost/m2 21.94	Retention % 0.72	Cost/m2 176	Retention % 0.5	
Area (m^2)	24		6		24		**N/A**
Retention (L)	864		216		600		**1680**
Cost (DKK)	2880		131.64		4224		**7235.64**

Revised Design 1: Retentions and Costs

Grass (with stepping stones)			
	Cost/m^2 79.50	Retention % 0.72	Totals
Location	3		
Area (m^2)	48.40	28.40	**76.80**
Retention (L)	1742.40	1022.40	**2764.80**
Cost (DKK)	3848	2258	**6106**

Flower Beds					
		Cost/m^2 689.95	Retention % 0.65		Totals
Location	1	4	8	12	
Area (m^2)	8.25	3.00	3.00	4.85	**19.10**
Retention (L)	268.13	97.50	97.50	157.56	**620.69**
Cost (DKK)	5692	2070	2070	3345	**13177**

Green Roofs				
		Cost/m^2 211.70	Retention % 0.53	Totals
Location	2	9	12	
Area (m^2)	20.50	20.50	18.85	**59.85**
Retention (L)	543.25	543.25	499.53	**1586.03**
Cost (DKK)	4340	4340	3991	**12670**

Planters				
		Cost/planter 1009.10		Totals
Location	5 (8 planters)	7 (8 planters)	11 (30 planters)	
Area (m^2)	1.92	1.92	7.19	**11.03**
Retention (L)	95.88	95.88	359.55	**551.31**
Capacity (L)	728.69	728.69	2732.58	**4189.96**
Cost (DKK)	8073	8073	30273	**46419**

Herb Garden		
	Cost/m^2	Retention %
	993.49	0.65
Location	6	
Area (m^2)	5.48	
Retention (L)	178.10	
Cost (DKK)	1987	

Revised Design 2: Retentions and Costs

Grass Grid			
	Cost/m^2	Retention %	
	125.79	0.72	
Location	3		Totals
Area (m^2)	48.40	28.40	**76.80**
Retention (L)	1742.40	1022.40	**2764.80**
Cost (DKK)	6088	3572	**9661**

Flower Beds				
		Cost/m^2	Retention %	
		689.95	0.65	
Location	1	4	8	Totals
Area (m^2)	8.25	3.00	3.00	**14.25**
Retention (L)	268.13	97.50	97.50	**463.13**
Cost (DKK)	5692	2070	2070	**9832**

Green Roofs			
	Cost/m^2	Retention %	
	211.7	0.53	
Location	2	9	Totals
Area (m^2)	20.50	20.50	**41.00**
Retention (L)	543.25	543.25	**1086.50**
Cost (DKK)	4340	4340	**8680**

Planters				
		Cost/planter		
		1009.1		
Location	5 (32 planters)	6 (12 planters)	around (12)	Totals
Area (m^2)	7.67	2.88	2.88	**10.55**
Retention (L)	383.52	143.82	143.82	**671.16**
Capacity (L)	2914.75	1093.03	1093.03	**5100.82**
Cost (DKK)	32291	12109	12109	**56510**

Additional Green Space		
	Cost/m^2 23.30	Retention % 0.72
Location	10	
Area (m^2)	60.00	
Retention (L)	2160.00	
Cost (DKK)	1398	

Herb Garden		
	Cost/m^2 993.49	Retention % 0.65
Location	6	
Area (m^2)	5.48	
Retention (L)	178.10	
Cost (DKK)	1987	

Bike Bench Planter		
	Cost/bench 1419.60	Retention % 0.65
Location	12	
Area (m^2)	3.00	
Retention (L)	97.50	
Cost (DKK)	4259	

Extend Tree Area		
	Cost/50L 19.95	Retention % 0.65
Location	13	
Area (m^2)	14.00	
Retention (L)	455.00	
Cost (DKK)	759	

Final Design: Retentions and Costs

Grass (with stepping stones)			
	Cost/m^2 79.50	Retention % 0.72	Totals
Location	3		
Area (m^2)	48.40	28.40	**76.80**
Retention (L)	1742.40	1022.40	**2764.80**
Cost (DKK)	3848	2258	**6106**

Flower Beds				
		Cost/m^2 689.95	Retention % 0.65	
Location	1	4	8	Totals
Area (m^2)	8.25	3.00	3.00	**14.25**
Retention (L)	268.13	97.50	97.50	**463.13**
Cost (DKK)	5692	2070	2070	**9832**

Green Roofs			
	Cost/m^2 211.7	Retention % 0.53	
Location	2	9	Totals
Area (m^2)	20.50	20.50	**41.00**
Retention (L)	543.25	543.25	**1086.50**
Cost (DKK)	4340	4340	**8680**

Planters				
		Cost/planter 1009.1		
Location	5 (32 planters)	6 (12 planters)	around (12)	Totals
Area (m^2)	7.67	2.88	2.88	**10.55**
Retention (L)	383.52	143.82	143.82	**671.16**
Capacity (L)	2914.75	1093.03	1093.03	**5100.82**
Cost (DKK)	32291	12109	12109	**56510**

Additional Green Space		
	Cost/m^2 23.30	Retention % 0.72
Location	10	
Area (m^2)	60.00	
Retention (L)	2160.00	
Cost (DKK)	1398	

Herb Garden		
	Cost/m^2 993.49	Retention % 0.65
Location	6	
Area (m^2)	5.48	
Retention (L)	178.10	
Cost (DKK)	1987	

Bike Bench Planter		
	Cost/bench 1419.60	Retention % 0.65
Location	12	
Area (m^2)	3.00	
Retention (L)	97.50	
Cost (DKK)	4259	

Extend Tree Area		
	Cost/50L 19.95	Retention % 0.65
Location	13	
Area (m^2)	14.00	
Retention (L)	455.00	
Cost (DKK)	759	

Appendix D: Supplementary Courtyard Design Tables

This appendix contains the retention and cost values for each design by strategy. All totals include only the additional retention provided by the proposed solutions. The total retention of the courtyard for each design also includes the current courtyard retention, 5,266 L (6.13%). The table of options provided to the courtyard committee is also included.

Current Courtyard	
	Retention (L)
Scattered Beds (12)	601
Scattered Trees (5)	325
Bushes by Entrance	910
Back Wall	910
Central Green Space	2,520
Total	**5,266**

Preliminary Design		
	Retention (L)	Cost (DKK)
Green Roofs	1,586	12,670
Grass Grids	2,779	9,542
Walkway Green Strip	216	139
Planters (30)	360	19,773
Rain Barrels (10)	3500 capacity	12,990
Total	**4,941**	**55,114**

Revised Design 1		
	Retention (L)	Cost (DKK)
Green Roofs	1586	12,670
Grass with Pavers	2765	6,106
Flower Beds	621	13177
Planters (46)	551	46,419
Herb Garden	178	1987
Rain Barrels (10)	3500 capacity	12,990
Total	**5523**	**93,348**

Revised Design 2		
	Retention (L)	Cost (DKK)
Green Roofs	1,087	8,680
Grass Grid	2,765	9,661
Flower Beds	463	9832
Planters (56)	671	56,510
Herb Garden	178	1,987
Green Space	2,160	1,398
Bench Planter	98	4,259
Tree Area	455	759
Rain Barrels (10)	3500 capacity	12,990
Total	**7,877**	**106,076**

Final Design		
	Retention (L)	Cost (DKK)
Green Roofs	1,087	8,680
Grass with Pavers	2,765	6,106
Flower Beds	463	9832
Planters (56)	671	56,510
Herb Garden	178	1,987
Green Space	2,160	1,398
Bench Planter	98	4,259
Tree Area	455	759
Rain Barrels (10)	3500 capacity	12,990
Total	**7,877**	**102,521**

Additional Strategy Options				
Location	Description	Options	Retention (L)	Cost (DKK)
1	Patio 1	Flower beds	268	5692
2	Shed 1	Green roof	543	4340
3	Clotheslines (both areas)	Grass with pavers	2765	6106
		Grass grid	2765	9661
4	Patio 2	Flower beds	98	2070
		Replace with grass	864	559
5	Left side of gate	Planters near swings (8)	96	8073
		Grass under swings/replace swings with grass	648	419
		Replace swings with planters (32)	384	32291
6	Central lawn	Herb garden in front of deck	178	1987
		Replace deck with lawn	1440	932
7	Right side of gate	Planters near sandbox (8)	96	8073
		Replace sandbox with lawn	216	140
		Replace sandbox with planters (32)	384	32291
8	Patio 3	Flower beds	98	2070
		Replace with grass	864	559
9	Shed 2	Green roof	543	4340
10	Basketball court	Replace with lawn/sport field	2160	1398
11	Planter area	Planters (30)	360	30273
		Replace with sandbox	N/A	N/A
12	Shed 3	Green roof	500	3991
		Replace with swings	N/A	N/A
		Bike parking planter benches	98	4259
13	Back wall	Extend soil one meter and increase vegetation	455	759

Appendix E: Survey Results

This appendix details the results of the online survey, identifying common themes and ideas.

Demographics

Age range		Occupation?		Rent or own living space		Living space type	
25-55	7	Consultant	2	Rent	5	House	2
56+	2	Student	2	Own	4	Apartment	7
		Senior producer	1				
		IT management	1				
		Pensionist/retired	2				
		Graduate	1				

Green Alternatives

What are your opinions of environmental sustainability?		What green alternatives do you know of that you could implement at home?		List factors that would be important when choosing a green solution for your home.	
Necessary/important	8	LED lights	2	Aesthetics	2
		Water conservation	5	Impact & efficiency	4
		Composting/waste reduction	2	Cost/return on investment	5
		Energy savings	5	Long-term	3
		Rainwater management	3		

Rainwater Management

What problems have you experienced from flooding?		What methods do you know of for managing rainwater on your property?	
None	4	Pipes/traditional methods	2
Basement	5	Green space/gardens	5
		Rain barrels	2
		Green roof	2
		None	1

Green Rainwater Solutions: Green Roofs

What do you know about green roofs?		What more would you like to know about green roofs?		Would you be willing to install a green roof on your property?		Why or why not?	
Absorb water	5	Installation/structural requirements	6	yes	7	yes: runoff decrease	4
Structural requirements	2	Costs/subsidies	3	no	1	yes: aesthetics	3
				unsure	1	no: not structurally feasible	2
						no: cost	1
						unsure	1

Green Rainwater Solutions: Rain Garden

What do you know about rain gardens?		What more would you like to know about rain gardens?		Would you be willing to install a rain garden on your property?		Why or why not?	
Nothing/not much	4	Structural requirements	4	Yes	1	Yes: hold rainwater	1
Prevent flooding	3	Cost	2	No	3	Unsure: want to know function	2
		Maintenance	2	Maybe	3	Unsure: want to know structural requirements	3
		Efficiency	2	Unsure	2	Cost	1

Green Rainwater Solutions: Rain Barrels and Storage

What do you know about rain barrels and other storage techniques?		What more would you like to know about rain barrels or other storage techniques?		Would you be willing to install a rain barrel or other storage technique on your property?		Why or why not?	
Have them	4	Installation	3	Yes	6	Yes: use water as a resource	3
Catch water	2	Why necessary	1	Maybe	2	Yes: decrease flooding	1
		Nothing/not much	4	Unsure	1	Unsure	2

Appendix F: Supplementary Images of Webpages

This appendix includes additional screenshots of the two webpages that we created on Miljøpunkt Amager's website. Note that all content of the webpages is not seen in the images below.

Webpage 1: Climate Adaptation Strategies for Rainwater Management

Example of the short description section of the climate adaptation webpage. The image on the following page shows the link to the courtyard page.

Green Roof

Publiseret d.: 27/04/2016 - 14:39

A green roof is a layer of soil and vegetation located on a building's roof that reduces runoff and provides green space in urban areas. They contain a waterproof layer to protect the original roof, a layer that allows for water drainage, soil, and vegetation such a moss or sedum [1].

Green roofs can be bought as premade squares or easily installed using the following materials found at hardware stores: a tarp, gravel, and a sedum mat or soil and seeds. Green roofs can only be installed effectively on roofs with slopes between 0 and 30 degrees, which makes them ideal for flat sheds or garages; the roof must also be able to support an additional 50 kg per square meter, so it is important to check the structural stability of the original roof [2].

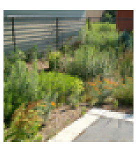
Green roofs add a recognizable green element to the area; they also retain almost all water in typical rainstorms.

1. Lee, J. Y., Moon, H. J., Kim, T. I., Kim, H. W., & Han, M. Y. (2013). Quantitative analysis on the urban flood mitigation effect by the extensive green roof system. 181, 257-261.
2. Technical Preservation Services. (2016). What is a Green Roof?
Retrieved from http://www.nps.gov/tps/sustainability/new-technology/green-roofs/define.htm

Del på facebook

Rain Garden

Publiseret d.: 27/04/2016 - 14:39



A rain garden is an area of vegetation located in a depression of 15-30 cm below the ground's surface; 30-60 cm below the depression is filled with soil and mulch [3].

The purpose of a rain garden is to collect water from surrounding flat or impervious surfaces and allow the water to infiltrate into the ground while also filtering out pollutants. Due to this, the depth at which the ground is saturated with water (the water table) must be taken into account to avoid a decrease in efficiency.

Directing water into the ground requires permits from the city of Copenhagen and the infiltration site must be at least 5 m away from foundations or basements of nearby residential buildings to prevent damages or flooding.

Rain gardens can be adapted to fit into virtually any space, with the option to add in water elements or creative shapes as well.

3. City of Gallatin. (2015). Rain Garden Diagram 2.
http://www.gallatin-tn.gov/wp-content/uploads/Rain-Garden-Diagram-2.jpg: City of Gallatin, TN.

Del på facebook

Planter

Publiseret d.: 27/04/2016 - 14:38

Planters are boxes containing soil and plants that also allow for water drainage. Some planters are self-watering since they contain a cavity under the soil for storing added rainwater that will be absorbed by the soil above when it becomes dry; this allows for filtration of pollutants and low-maintenance urban agriculture. Planters can also be filled completely with soil or placed on wheels so as to allow them to be moved around and brought inside during colder months.

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Rain Barrel

Publiseret d.: 27/04/2016 - 14:38

Rain barrels can be easily used to store rainwater runoff from roofs for reuse. This water may contain pollutants picked up from hard surfaces, making it not suitable for consumption or directly watering food plants. However, the rainwater collected can be added to the storage area of self-watering flower beds since the plants and soil will filter it. The water may also be used for irrigating green spaces or washing hard surfaces such as buildings and walkways.

Rain barrels can help reduce the stress on the water drainage system when attached to gutter downspouts. Since the amount of water a rain barrel can hold is limited by its capacity, a branched connection can be included to allow additional water to bypass the rain barrel and flow directly through the downspout to the sewers.

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Example of an Adapted Courtyard

Publiseret d.: 27/04/2016 - 14:38

An example courtyard adaptation plan that utilizes several of the solutions detailed above was designed by a group of college students from the USA. The design takes into account the amount of rainwater that the courtyard experiences in a 10-year rain event, the cost of each strategy, and also the ease of installation.

To read more about the design, go to **this page**

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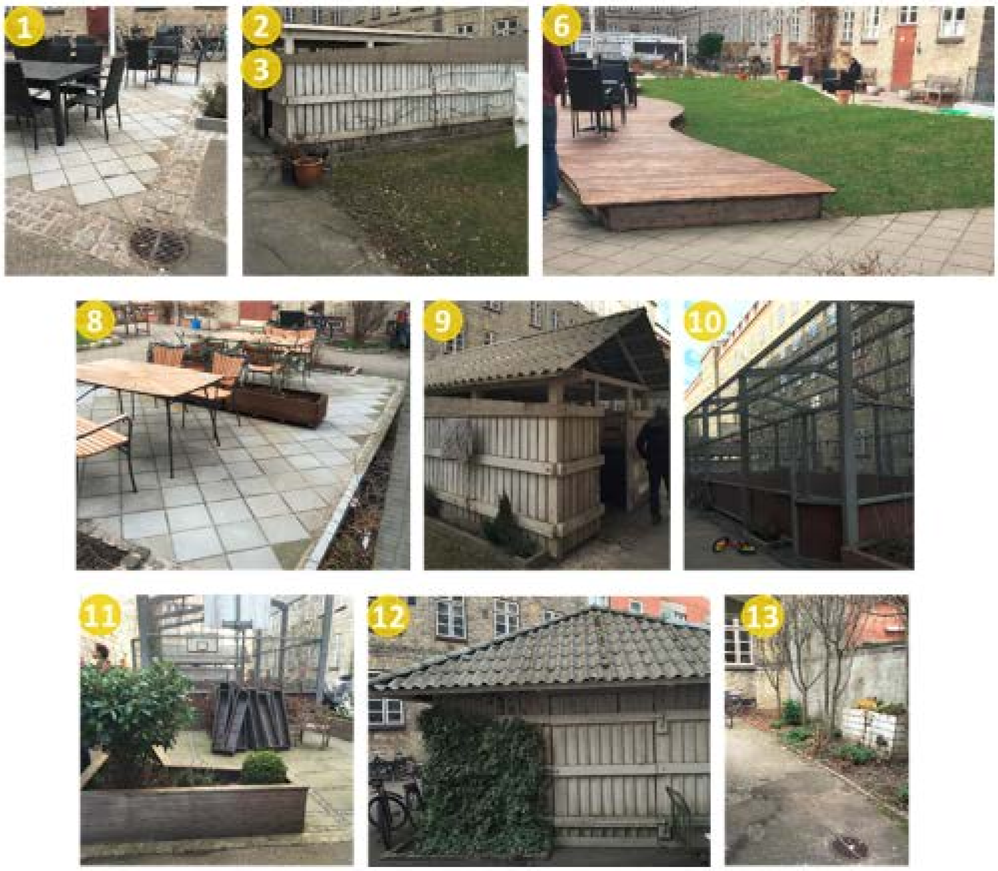
Webpage 2: Example Courtyard Design

Additional screenshots of the in-depth courtyard webpage.



The current layout

1: Large patio with drains connecting to the city sewer system and a small raised flower bed
2: Small, flat-roofed shed for trash and recycling receptacles
3: Clotheslines for drying laundry over cement tiles with grass growing between them
4: Small patio next to a walkway with raised flower beds on three sides
5: Small swing set near the entrance to the courtyard
6: Central green space sloped towards a wooden deck
7: Sandbox near the entrance to the courtyard
8: Small patio next to a walkway with raised flower beds on three sides
9: Small shed with a slanted roof for trash and recycling receptacles
10: Small fenced in basketball court with a fenced roof
11: Planter patio area with four, V-shaped corner planters
12: Large wooden shed with a slanted roof
13: Large garden area along back wall with a few trees and shrubs

Proposal for a new layout

After discussing different strategies and approaches with the courtyard committee, a final design with an estimated cost of DKK 89.529 was proposed, which incorporates different solutions based on the layout of the courtyard and the needs of the community.

With this design the courtyard is estimated to retain 13,142 L in a 10-year rain event, which is 15.3% of the rain that the falls in the courtyard and a 150% increase in retention when compared to its current state.

Below is a picture of the final design with each adapted area numbered and the solutions incorporated described below.

Flower beds: Flower beds were added around the edges of the patios at locations 1, 4, and 8. This allows for the water from nearby impervious surfaces like patios to be retained by the ground while adding in aesthetic appeal.

Planters: Homemade planters were added to locations 5, 6, and 7. These small moveable planters are self-watering and can therefore store water from rain barrels as well. This will allow for more water retention while also incorporating social interaction between the members of the housing development as they grow plants, herbs, and food together in their individual planters.

Green roofs: Homemade green roofs were added on the trash sheds at locations 2 and 9. This strategy absorbs almost all rainwater from a typical rain event and decreases the amount of runoff onto the nearby patios and pavement.

Grass with pavers: The small cement tiles under the clotheslines at location 3 were replaced with grass and pavers. The pavers would prevent the area from becoming muddy for people walking through while increasing green space within the courtyard.

Herb garden: An herb garden was added along the deck in location 6. This raised bed retains water like a planter but is not enclosed on the bottom, allowing water to seep into the ground. The goal of this space is to have a shared community herb garden in a central location for everyone to utilize.