IOP Conference Series: Materials Science and Engineering



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To cite this article: Haiyun Xu *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1203** 032063

# Building Climate Resilient City through Multiple Scale Cooperative Planning: Experiences from Copenhagen

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**Abstract**. Copenhagen, as one of the well-known European green capitals, has dedicated efforts to implement a series of policies and take action on climate adaptation strategies from 2008 to 2020 to address the challenge brought by global warming. Climate adaptation in new urban planning for stormwater management opens up the dialogue in-between new possibilities for cooperation with multiple stakeholders and climate adaptation projects are developed in multilevel governance. However, in many cities, the organizational capacity of multiple stakeholders at the various level required to combine climate resilience with further sustainability targets may not be available. The paper focuses on the Copenhagen climate adaptation case, and further explores how the city strategically meta-govern the boundaries between the expert governed large-scale water management scheme against small-scale place-based bottom-up projects in collaboration with citizens and other place-based stakeholders. Furthermore, we summarize the experiences of building a climate adaptation city in Copenhagen, which refers to adequate data preparation in the early stage and rigorous planning, well- integration of stormwater management design & landscape design of urban space coordination of various stakeholder's interests and public participation. Key words: Climate change adaptation; Urban stormwater management; Sustainable cities; Public participation; Green infrastructure

## 1. Introduction

Climate change has become an important factor affecting global sustainable development. The IPCC addressed that many parts of the world have in recent years experienced the disasters caused by climate change, including sudden extreme weather events, such as floods, storms, droughts, high temperatures, heat waves, and cold waves, and slow changes, such as sea level rise. [1]. These climate disasters are believed to cause threats and risks that will affect the lives, health, assets, and services of cities or societies in the future. The disaster risk for cities is often the result of the interaction between the climate disaster itself and the vulnerability of the city itself.

Cities are dense areas of population and capital. The impact of urban structure on urban climate has exacerbated the urban rain island and heat island effect; the high emissions of carbon, heat, and pollutants in cities also affect climate change and generate new disasters; dynamic cities The process of urbanization has also brought about changing risk patterns. In addition, the high density of urban population, buildings, and infrastructure has formed the fragile conditions of the city itself, and the infrastructure is difficult to effectively respond to extreme climate changes; urban expansion has destroyed the original vegetation, such as Windbreaks, wetlands, ventilation corridors, etc., these are important spaces for rainwater penetration and air cooling. It can be seen that climate change and rapid urbanization are the main driving forces that exacerbate the risk of urban climate disasters. Cities have contributed to and are also victims of climate change. [2].Therefore, the disaster risk brought by climate change also poses new challenges to urban planning. The establishment of a climate-adapted city that effectively responds to climate change will become an important topic of urban planning.

The climate change adaption city is one that is prepared for existing and future climate impacts through improving resilience of city, thereby limiting their magnitude and severity. Planning cities for adaptation to climate change has emerged as a central component of climate policy over the last decade[3,4]. An increasing number of cities around the world have begun to plan for climate change by developing stand-alone climate plans or incorporating climate considerations into existing urban planning, and given names such as sponge city [5], sustainable drainage systems (SuDS) [6], green (stormwater) infrastructures (GI/GSI) [7,8] and low impact development (LID) [9]. Existing literature addressed that these climate change adaption strategies could improve infrastructures and contribute to increasing resilience of the city through linking stormwater management to water supply through stormwater harvesting or groundwater, increasing biodiversity and ecological performance, and conserve the regional ecosystem by designing stormwater management features that can compensate for the loss of nature and natural space, and increasing livability and socioeconomic sustainability by introducing green infrastructures that improve aesthetics, recreation, and social inclusiveness [2, 10]. Contrary to the mono-functional discharge target of conventional pipe-based stormwater management, the achievement of building climate adaptation city relies on not only from technical disciplines but also the cooperation of multiple fields including the life sciences, humanities, and economics. Moreover, the practices of climate adaptation strategies not only refer to the transformation of underground pipeline network but also intertwining climate adaption above-ground design with the urban surface and planning, which requiring negotiation and cooperation among multiple stakeholders from municipality level to the community level.[11] However, in many cities, the organizational capacity of multiple stakeholders at the various level required to combine climate resilience with further sustainability targets may not be available. The objective of this paper is to present an overview of the climate adaption strategies of Copenhagen in a multilevel governance framework, and explore how the city strategically meta-governs the climate adaption strategies between the decision-makers governed municipality level water management scheme against small-scale place-based community projects in collaboration with citizens and other stakeholders[12].

## 2. Background of Copenhagen and its Climate Change Adaptation Policy

Copenhagen, the capital of Denmark, has a temperate maritime climate with mild seasons and rainfall, and the most frequent rainfall is between July and August. Over the past few years, Copenhagen has confronted the pressure of climate change, the most severe of the two floods in 2011 and 2014, which surpassed the "once-in-a-century" rainfall. The Danish Meteorological Institute (DMI) expects extreme weather such as forceful rainfall and longer drought cycles will become more prevalent in Denmark. Copenhagen will encounter difficulties from rising sea levels and frequent rainfall (Figure 1). Besides, peak summer temperatures in Copenhagen are projected to increase by 2°C to 3°C by 2050. By 2100, the rainfall intensity of a 10-year rainfall event will rise by 30 to 40%; The seawater level around the city will increase by about 1 meter in the following 100 years. Climate change will keep threatening the growth of cities [13,14]. The city of Copenhagen aims to become the first carbon-neutral capital in the world by 2025. However, the cloudburst events and floods reminded people that the city life of Copenhagen would be directly and fundamentally challenged by extreme weather. Climate adaption becomes urban planning and policymaking priority in Copenhagen. Since 2012, the Copenhagen City Council has started developing a range of adaptation policies to address extreme weather and climate change [13-16]. In climate change adaptation policies and projects, the Copenhagen Municipality has also adopted the update of the Urban Sustainability Concept from the United Nations in 2015. Additionally, it has combined sustainable development goals comprising social, economic, and environmental aspects and later developed an action plan to practice sustainable development [17]. Thus, the Copenhagen climate change adaptation policy is developed to deal with more frequent stormwater in Copenhagen in the future while being able to support integrated social, economic, and environmental sustainability and the improvement of the quality of life of residents to carry out the objects of the UN urban development [18].

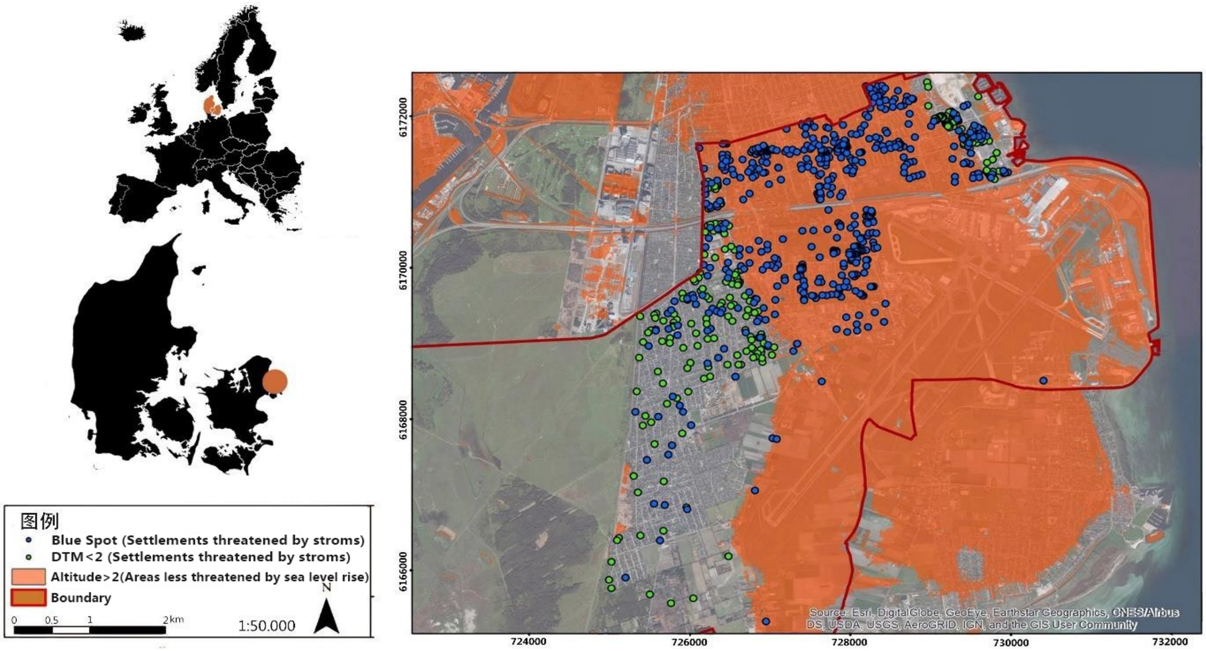


**Figure 1.** The location of Copenhagen and the spatial pattern of stroms and sea level rise threats.

## 3. Climate Change adaptation strategies in municipality level.

### *3.1. The climate adaptation policies*

Since 2011, the Copenhagen Municipality has developed the following key climate change adaptation policies (Table 1) to address the urban stormwater challenges of climate change and support sustainable urban development.

In the plan, the Municipality states that climate change planning is not a passive method but will be an excellent chance for urban development. It will assist in generating a greener city and present more jobs. The plan sets out three levels of climate change adaptation measures for the urban management area: [13]

Measure 1 is the adaptation of infrastructure, comprising the expansion of sewerage capacity, passive construction of pumping stations, and dams to manage climate change. This measure is adopted to sites where there is a risk of extreme damage from climate change, and the Municipality takes this measure first to prevent damage. By contrast, if Measure 1 is executed citywide, it will be costly and have a considerable long-term negative influence on traffic and urban business activities during implementation. Accordingly, if it is feasible, the following measure 2 is more suggested.

**Table 1.** Overview of the leading climate change adaptation policies of the Copenhagen Municipality

| Name | Year of development | Main objectives |
|---|---|---|
| (1) Copenhagen Climate Adaptation Plan | 2011 | It is maintaining the capacity of existing sewer systems to cope with once-in-ten-year rainfall events by 2100, despite the challenge of a 30% increase in rainfall intensity for once-in-ten-year rainfall events.<br>Construct livable cities, decrease the urban heat island effect, and complete urban green growth [11,14]. |
| (2) The City of Copenhagen Cloudburst Management Plan | 2012 | Strategies and objectives for coping with extreme rainstorms in Copenhagen.<br>To guarantee that Copenhagen's climate change adaptation targets are reached while preventing flooding during extreme weather and keeping the urban surface water to 0.1 m in deal with more frequent flooding over 100 years [11,16]. |
| (3) Climate Change Adaptation and Investment Statement | 2015 | The implementation plan is based on the City of Copenhagen Cloudburst Management Plan in 2012 and describes the inputs, effectiveness, and challenges of the climate change adaptation plan [17]. |

*3.1.1. Copenhagen Climate Adaptation Plan*

Measure 2 is to detain stormwater within the urban site and disconnect stormwater from the sewer at the building street to flow into a storm sewer or Sustainable Urban Drainage System (SuDS). At the same time, it reduces the proportion of stormwater discharged as much as possible into the combined urban drainage network. Under the same circumstances that can deal with urban stormwater, the use of Measure 2 will be far less than the investment of Measure 1. In Measure 2, stormwater is adopted as a resource. Since retaining stormwater on urban sites helps mitigate urban flooding and enhance urban recreational space, presenting irrigation water for urban green spaces and the water environment. As a result, Measure 2 is promoted to the entire urban area.

Moreover, there are measure 3 assures that floodwaters are discharged only to the relatively least damaging areas in extreme rainfall situations. For instance, by re-routing selected floodways based on existing stormwater runoff paths, streets are utilized to direct stormwater to less impactful areas such as sports fields and parks.

*3.1.2. The City of Copenhagen Cloudburst Management Plan*

"Cloudburst" is a term applied by the Danish government to define a short period of intense rainfall. The Danish Meteorological Institute (DMI) determines it as a rainfall event with more than 15 mm of precipitation in 30 minutes. As an offshoot of the climate change adaptation plan, the Copenhagen Municipality has drafted its strategy for managing extreme rainfall in four prospects. 1. With certain measures to improve the urban resilience to flooding; 2. Develop regional flood protection levels for the city; 3. Separate the transformation implementation region and customize the priority level; 4. Legislation formulation, responsibility assignment, and financial planning [15].

Firstly, the traditional drainage system in Copenhagen principally utilizes a combined sewerage network, which is designed to discharge rainfall up to a 10-year return period. Nevertheless, in global climate change, the growing frequency of extreme rainfall has occurred in a shortage of original drainage design volume. In order to enhance urban resilience against waterlogging and decrease overall renovation costs, specific measures essentially involve i) Stormwater requires to be classified from municipal wastewater to satisfy the drainage requirements of future extreme rainfall. ii) The main runoff generated by the rainstorm is mainly directed to the harbor, while the rest is designed to discharge to the lake water bodies in the city center. iii) Apart from infiltration, stormwater detention is also used as another important measure. For example, low-lying green belt areas can be designed as stormwater detention zones. The application of constructed canals or new tunnels as flood channels to increase urban drainage capacity; Make full use of the combination of stormwater landscaping and green infrastructure, observing it as an enabler to generate blue and green urban infrastructure in the city. In practice, regarding the difficulty of updating the combined pipe network to a rain and sewage diversion pipe network in the short term, it is essential to respond more flexibly to extreme precipitation. The plan suggests the need to use more spaces such as streets, squares, and green spaces to divert or stagnate rainwater at the surface in the future, thus diminishing the amount of rainwater discharged to the urban pipe network [10,15].

Next, from an economic point of view, Copenhagen scholars claim that urban flooding standards cannot completely cover all rainfall, particularly extreme rainfall with high intensity and low recurrence periods. Accordingly, the depth of water on the road surface is allowed to be restricted to 10cm. Furthermore, by connecting probabilistic statistics and economics, the urban flooding risk is assessed by cost-benefit analysis to reach the optimal economic flooding solution.

Again, implementing a comprehensive extreme rainfall response plan cannot be completed overnight because of government budget restrictions. Hence, Copenhagen has composed a 20-year long-term retrofitting plan. Copenhagen was separated into various flood control zones according to catchment areas. In addition, each area is prioritized according to its flooding risk and ease of retrofitting, and the retrofitting plan is implemented in stages over diverse periods.

Eventually, the current legislation does not present the best assistance for extreme rainfall from an environmental and financial perspective. Consequently, the plan states a funding model that attracts a combination of public and private investment and assigns responsibility for implementation to at least private landholders, utility companies, and city administrators, if not more.

*3.1.3. Climate Change Adaptation and Investment Statement*

This statement further describes the background and objectives of the Copenhagen Stormwater Plan, which establishes the implementation plan and deploys around 300 implementations. The plan declares that if we do not do something about climate change in the face of climate change, we cannot do anything about it. The plan states that collapse to act in the face of climate change could cost Copenhagen 16 billion Danish kroner and that the corresponding expansion of the sewerage network will cost at least 20 billion kroner. Notwithstanding, if the Copenhagen Stormwater Plan is selected, only 12 billion kroner will be needed for surface conveyance and storage of rainwater. The combination of surface conveyance and storage solutions is much more flexible than large pipeline solutions and requires to be broadly promoted in climate change response projects.

The statement further defines four types of climate change adaptation solutions in Copenhagen, including i) the construction of "stormwater paths," where roads are realigned, the topography is changed, or curbs are raised to build a floodway for extreme rainfall. In principle, there is no green vegetation on the path, and its primary function is to drain the stormwater instantly. ii) the construction of "detention roads" that combine multiple detention elements into the road, such as curbs and similar physical elements to retain and store stormwater, usually with great chances to incorporate urban spatial improvements to serve urban green or blue infrastructure plans. iii) Designing detention spaces to retain and collect stormwater by formulating low-lying terrain, utilizing spaces such as sunken parking areas, plazas, sports fields, etc., and applying topography to design and develop multifunctional urban spaces. iv) It is a "green road", which uses smaller roads (such as shared roads in residential areas) to eliminate and store rainwater runoff naturally locally. These different scenarios can be applied in diverse combinations depending on the actual site needs [16].

Above all, the three climate change adaptation policies in Copenhagen are concentrated on addressing urban stormwater, and the city has invested more in climate change adaptation initiatives for urban stormwater.

### *3.2. Initiatives for Climate Change Adaptation projects*

According to these policies, the climate change adaptation initiatives for urban stormwater management in Copenhagen are two-fold. One is to generate different methods throughout the city to detain heavy stormwater so that they do not enter or delay access to the urban rainwater pipe network, and largely apply urban roads as flood discharge channels; The other one is developing blue and green infrastructure to slow rainfall runoff and reduce flood risk.

In advancing climate change adaptation, the Copenhagen Municipality recognized that immediately increasing the size of the city's stormwater network was a time-consuming and costly decision and would not be enough to address climate change. Urban surface drainage channels can reduce the pressure on the existing stormwater network.

Additionally, the construction of blue-green infrastructure to detain urban stormwater and delay its entry into the urban network is being promoted throughout the city as a major initiative to promote climate change adaptation in Copenhagen.

In this context, the Copenhagen Municipality has sketched a plan to promote 300 of these projects in its climate change adaptation and investment statement in 2015. The development of these projects is under a detailed analysis of river zoning, topography, pre-existing drainage systems, site conditions, and a plan for integrating water patterns with urban space. Copenhagen Municipality and HOFOR will jointly fund the operation of these 300 projects. The 300 projects will not be launched simultaneously, but a few start-up projects will be chosen each year. The choice of the project is based on the situation of urban development and reconstruction and the report of the Copenhagen Technical and Environmental Management Committee for the diverse water areas of Copenhagen in June 2014 [16]. The Copenhagen climate adaptation strategy therefore relies on a process of public–private ‘co-creation’; the participation of citizens, small businesses and other nonpublic actors in designated areas to remodel the city scape, adapting squares, streets, lakes, and parks to better cope with future cloudbursts. In the operation of the projects, municipalities can decide to develop them in cooperation with local communities and residents. Apart from the design of stormwater management, improvements and upgrading work to urban spaces can be comprised in the project costs. These 300 projects help mitigate stormwater and flood damage, provide public spaces for residents, enhance community participation, and bring meaning to future urban spaces.

During the construction of the 300 blue-green infrastructure stormwater detention projects, the city systematically categorized the projects and regularly summarized the solutions and design approaches applied in the 300 projects. Among them, the Østerbro Climate Change Adaptation Neighborhood, the first community project of climate change adaptation plan, converted Copenhagen's flagship pilot to show how to renew urban spaces and address climate change with innovative and sustainable solutions.

## 4. Climate Change adaptation strategies in community level: Case of Østerbro Climate Change Adaptation Neighborhood

The neighborhood is placed in the St. Kjelds neighborhood in Østerbro, north of Copenhagen. The neighborhood has a total area of 270,000 m2 [19] and is a peaceful neighborhood consisting mainly of old houses from the 19th to the first half of the 20th century. Massive rains in 2011 prompted the local government to concentrate the neighborhood's renovation on addressing the challenges of climate change. The project was commissioned by the Copenhagen Municipality and composed by landscape firm GHB and SLA in collaboration with the local Østerbro Environmental Center and community residents. The purpose is to transform Østerbro into one of Copenhagen's best green spaces while improving the infrastructure to make it more resilient to climate change in response to the high levels of rainfall brought by the extreme weather in Denmark over the past few years [20]. The project plans to produce 50,000 m2 of green space, and slowly disconnect 30% of the stormwater from the underground mixed storm sewer network [19].

The climate change adaptation neighborhood project was formally launched in 2012 [19,20]. At the beginning of the program development, the design team and the Municipality held discussion conferences with residents and community representatives about the project's design and function vision. In 2013, a public meeting was regulated to bring together more than a thousand people to reach the project site and contribute their ideas and views to the project. Throughout the project, public participation was achieved through interviews, questionnaires, planting events, resident dinners, workshops, and project panels. More than 10,000 people in the neighborhood participated in the project activities and had the right to be notified. Hence, the initial program of the project incorporates the public's interest. The Copenhagen Municipality considers that involving the residents in the development and planning process of the urban space will adapt the urban space to the specific conditions and life of the area. This process is required to notify the residents about the project, reassure them about the construction process's inconvenience, and make them more cooperative in its implementation. In addition, it will be more cooperative in the implementation of the project and encourage the participation of community residents in the follow-up maintenance and management to promote the subsequent healthy development of the project. The main purpose of this project is to transform local public spaces into climate adaption green spaces with rainwater treatment facilities such as roof rainwater harvesting and underground water storage systems, and retention green areas. The project consists of clime adaptation squares, and several small street-side green spaces(Figure2A), as well as green roofs, rain gardens, and other micro- blue-green infrastructure projects. The whole program utilizes green roofs, rain gardens, rain plazas, and other detention facilities to manage stormwater through delay and evaporation, collection and reuse, generating natural urban spaces while managing stormwater more naturally and efficiently at street level. It also enhances neighborhood biodiversity and improves the quality of life of residents [19,20]. Among them, Tåsinge Square is the first project of the climate adaptation neighborhood (Figure 2B.). The plaza consists of a slope of grass in the west, an activity space in the middle, and a stormwater rainforest in the east (Figure 2B), and the entire terrain slopes from west to east. During rainfall, the rainwater in the square is finally collected in the low-lying rainforest on the east side (Figure 2C). This rainforest consists of three sunken green areas of varying depths and sizes, planted with moisture-tolerant plant communities. The sinking design of rainwater rainforest accomplishes rainwater retention and infiltration and finally prevents rainwater from directly entering the urban pipe network. The activity space in the middle is equipped with a water drop sculpture, umbrella sculpture and pumping board, and recreation and leisure facilities. Underneath the sculptures, rainwater filtration and purification, and storage facilities are placed. Rainwater from the roofs of the surrounding neighborhood is directed and collected here. Meantime, the pumping board device enables children to play and pump the purified rainwater from the underground storage tank to the surface, where it is guided into the rainforest by the small channels on the surface. In this process, the presence of rainwater is presented an exciting form, and while achieving climate change adaptation, it promotes interaction with the residents and advances the experience of utilizing the site. Nowadays, the project delays and infiltrates about 8,000 m2 of rainwater from the site [11], making it the flagship of climate change adaptation projects in Copenhagen.

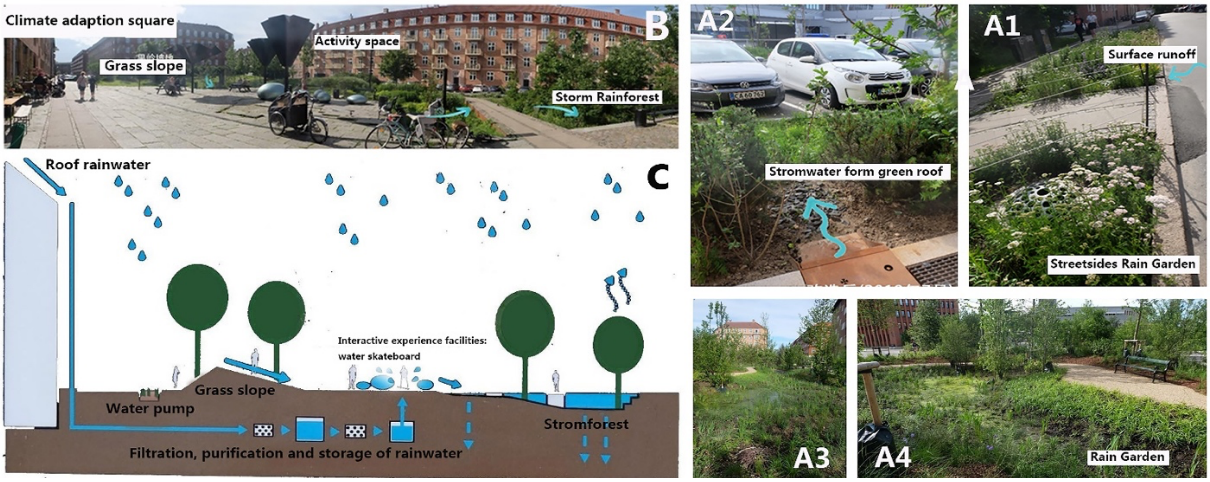


**Figure 2.** Climate adapation model and projects in the community

## 4. Discussions and conclusions

### *5.1. Pre-project In-depth Data Preparation and Analysis*

Copenhagen's climate change adaptation policy and management conduct are based on a sufficient systematic analysis of flood risks in Copenhagen. This is because the Municipality considers that only a clear understanding of the actual flood risk status will further action. Consequently, the concept of screening climate change risks is proposed. The concept combines information on topography, sea-level rise, storm surges, rainfall/runoff distribution within the Municipality, and the economic value of regional properties. This unified information is adopted to develop a climate change risk map based on parcel conditions. All of the above relevant information within the Municipality is collected into the GIS to form regional maps that can view the spatial extent and depth of flooding and present the economic value of properties, infrastructure, etc. The climate risk map will classify the most critical or advantageous areas to protect, such as recreational areas, businesses, and infrastructure, each provided a priority ranking for addressing climate change.

### *5.2. Close Integration of Stormwater Management Design with the Landscape Design of Urban Spaces*

In the context of urban land constraints, Copenhagen has intimately connected climate adaptation planning and urban development by synergistically combining blue-green infrastructure for climate adaptation functions with urban public space. As a result, integrating stormwater management with urban spatial landscaping has turned into the mainstream explication to support climate adaptation planning in Copenhagen at the policy level. It is implemented in urban master plans and urban project developments: For instance, if communities build public green space projects and developers develop housing areas, climate adaptation elements must be deemed part of the development project; hence, connecting urban spatial design and stormwater management and helping to leverage financing to expand the scope of climate adaptation planning. Copenhagen has achieved climate adaptation planning at the urban landscape design level by refurbishing streams, canals, lakes and transforming more green spaces to combine the urban public space's landscape and stormwater management functions. These projects have transformed public spaces into permeable pavement, sinking green spaces and green belts, rain gardens, flood ponds, pocket gardens in the community, green roofs, blue-green infrastructure Copenhagen from the local to the whole. It also has both the landscape and the social benefits of community residents' leisure and entertainment. These projects address climate change while generating new green spaces, presenting a pleasant and energetic area for public recreation and leisure when it is not raining, thus growing urban livability. Therefore, close integration of stormwater management design and urban landscape can spatially reach the various functional requirements of cities more efficiently and synergistically for sustainable urban development.

### *5.3. Coordinating with multiple vc gergy and promoting public participation*

In Copenhagen, public participation is an essential part of the execution of urban planning projects, and public will and opinion greatly influence the process of the final project proposal. During the project implementation process, residents, the design team, and the city's experts coordinate and provide their knowledge. Residents provide their requirements for the project based on their desires and demands, and the design team interprets the numerous public comments into a project proposal.

In the same way, the Copenhagen Municipality has been able to mobilize each party in the community to realize long-term economic, environmental, and social benefits in implementing climate change adaptation projects. Since different sites have diverse capacities to manage stormwater, the Copenhagen Municipality realized that it does not establish uniform retention or design return period. Accordingly, the technical solutions introduced by design practitioners for each project were largely respected.

Public participation is also a significant part of the design process. Only through the participation of residents, who are more aware of the goals and details of the site's stormwater management, can the design practitioners more correctly manage the stormwater and urban space within the site. In this process, residents are involved in the actual work, and the design component is the implementation of their vision. Public participation also allows residents to develop a more powerful sense of community belonging from their involvement in their neighborhoods.

In Copenhagen's climate change adaptation process, the higher the site's ability to retain stormwater, the better the community feedback on the project, and the more government funding for the project. Such a mechanism supports motivating the designers and the community better to contribute to the project. These investments are also far less than the cost of simply thickening or replacing the stormwater network while decreasing the influence on residents' amenities.

By coordinating various stakeholders in the implementation of the project, the Copenhagen Municipality has saved more money and could mitigate urban stormwater more sustainably in the process. Conformably, it inspires new neighborhoods, new opportunities for creativity, and new active and healthy lifestyles, carrying out long-term economic, environmental, and social benefits.

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