Practice and Evaluation of Sponge City Strategies for Flash flooding mitigation in Mediterranean Coastal Cities

A case study of El Poblenou, Barcelona

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INTRODUCTION

With global climate change, storms and floods have affected many cities around the world, and coastal cities are under greater threat.

The Urban drainage systems have developed for a long time, and "Sponge city" is a new generation of sustainable and flexible urban drainage systems based on the LID (Low Impact Development) concept to adapt to environmental changes and respond to natural disasters, which has shown significate effects in flooding mitigation in many practices.

In this study, we selected El Poblenou of Barcelona as study area, constructed an urban inundation model based on topographic and precipitation data, simulated and visualized urban flood events in two scenarios of sponge city strategies.

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STUDY AREA AND DATA

Study area

The study area is El Poblenou, which is a neighborhood of Barcelona (Sant Martí district) that borders the Mediterranean Sea to the south, Sant Adrià del Besòs to the east, Parc de la Ciutadella in Ciutat Vella to the west, and Sant Andreu to the north.

It has a land area of 1.577 km2 and a population of more than 30,000 habitants.

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STUDY AREA AND DATA
Land information

In order to obtain a surface elevation map with high resolution and accuracy, we processed the LIDARCAT2 point cloud data of ICGC

- Classify
- Remove the interference points
- Obtain the ground surface and building points
- Extract value into the topographic map

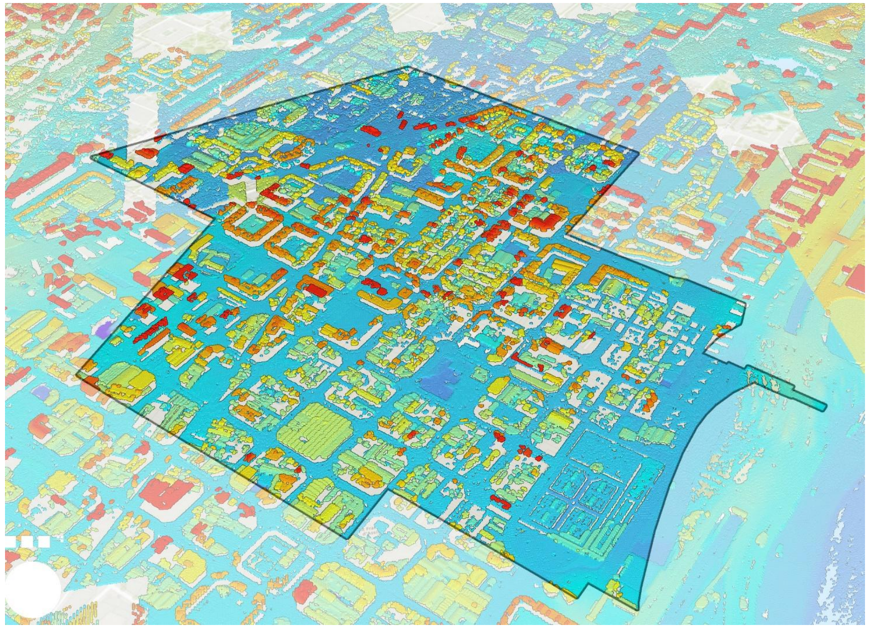

Figure 1. LIDARCAT2 point cloud data of El Poblenou

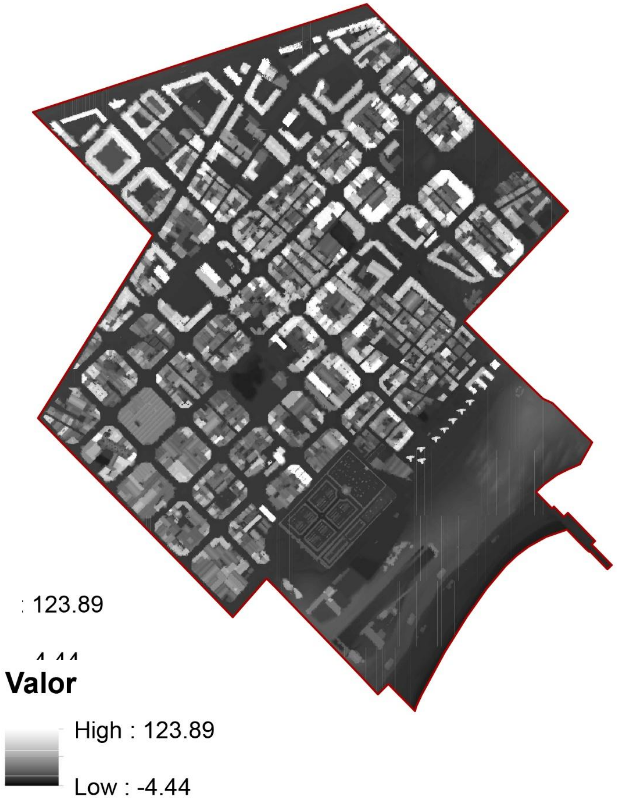

Figure 2. Surface elevation map of El Poblenou

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STUDY AREA AND DATA
Land information

Copernicus' Urban Atlas provides land cover and land use data, we can identify land types and obtain CN values through TR-55 manual (US Soil Conservation Service, 1986).

In the Figure 3, we can see the CN value corresponding to different land cover types.

Land Cover	CN	Land Cover	CN
Building Roof	98	Green urban areas (>75%)	74
Urban fabric (>80%)	95	Green urban areas (<50%)	89
Urban fabric (50%-80%)	86	Greening of Roads	86
Urban fabric (30%-50%)	82	Sand	63
industrial, commercial, public	95	Gravel	88
Road	98	Water	/

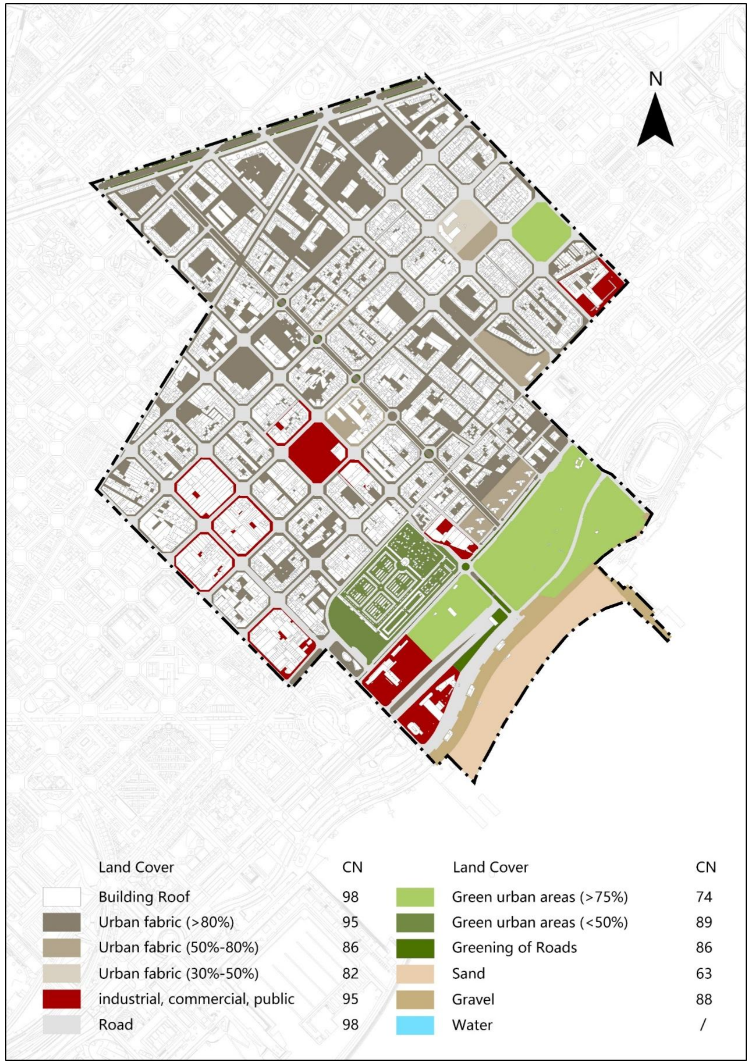

Figure 3. Land Cover of El Poblenou

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STUDY AREA AND DATA
Rainfall information

There are two types of rainfall used in the territories of the metropolitan area (Table 1):

In this study, we will simulate the rainfall-runoff model with the one-hour precipitation of a 100-year heavy rainstorm. The amount of precipitation is 69mm.

According to the design of sanitation network, the drainage speed is about 20mm per hour, so the total drainage water we can estimate as 30,000 m3.

Table 1. Rain design

Rain Type A (Zone Delta Llobregat)				Rain Type B (General zone)			
T	I_5, max	I_1	P_d	T	I_5, max	I_1	P_d
1	114	32	65	1	99	28	60
10	210	59	135	10	183	52	120
25	242	68	170	25	210	59	150
50	262	74	190	50	228	64	170
100	281	79	215	100	244	69	200
500	319	90	285	500	277	78	255

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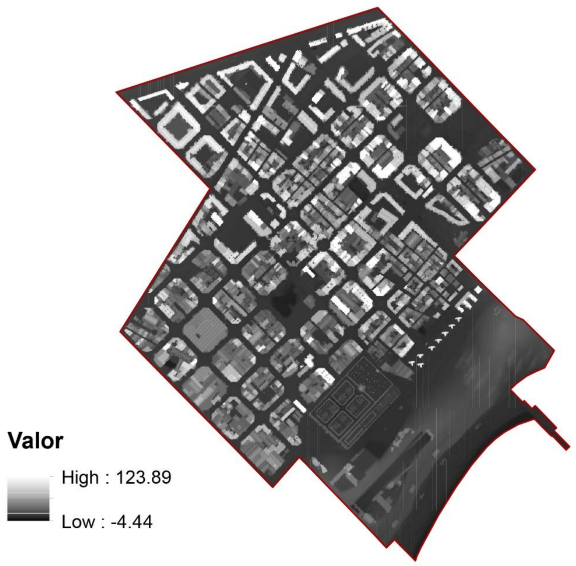
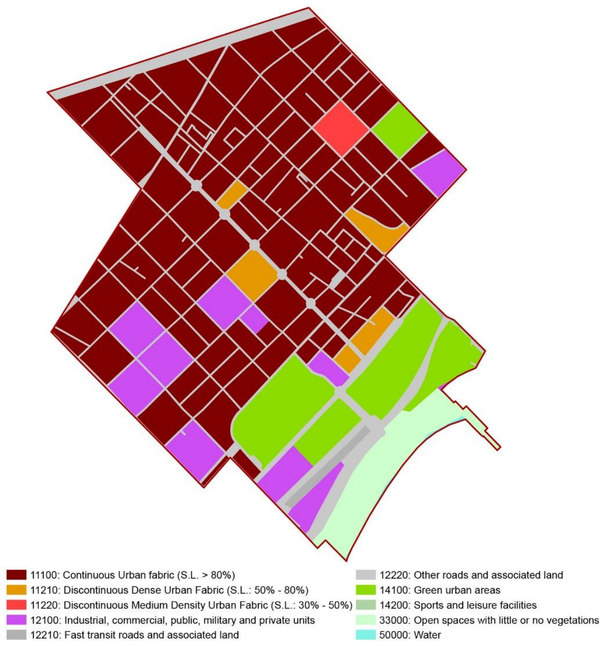
METHODOLOGY

Terrain model

The terrain model can be obtained from topographic maps, surface elevation maps, and land cover maps. It should be able to fully display the three-dimensional land information of the study area, including land cover type, elevation, etc.





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METHODOLOGY
Rainfall-runoff model

The rainfall model can be expressed by the water balance equation, as shown in Equation (1):

$$\mathbf{Q_r = Q_{\mathit{p}} - Q_f - Q_d - Q_e} \qquad (1)$$

where Qr – amount of surface runoff;
Qp – total precipitation volume;
Qf – amount of infiltration;
Qd – amount of drainage water;
Qe – amount of evaporation;

Due to the short duration of the storm we studied, evaporation (Qe) may be negligible in this paper. Therefore, the equation can be written as equation (2):

$$\mathbf{Q_r = Q_{\mathit{p}} - Q_f - Q_d} \qquad (2)$$

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METHODOLOGY
Rainfall-runoff model

In this model we mainly study the increase of infiltration and the decrease of surface runoff. The amount of infiltration mainly depends on the infiltration capacity of the soil in the study area.

The Soil Conservation Service curve number (SCS-CN) method proposed by the US Soil Conservation Service (1986) has been considered as a broad and practical tool in many studies (Jiao et al., 2017), so we can query the CN values according to the land information obtained in the terrain model to calculate the estimated infiltration, as shown in Equation (3):

$$\mathbf{R} = \begin{cases} \frac{(\mathbf{P}-\lambda\cdot\mathbf{Sr})^2}{[\mathbf{P}+(1-\lambda)\cdot\mathbf{Sr}]} & \textbf{when } \mathbf{P} \geq \lambda \cdot \mathbf{Sr} \\ 0 & \textbf{when } \mathbf{P} < \lambda \cdot \mathbf{Sr} \end{cases} \tag{3}$$

where R – direct runoff;
P – amount of precipitation (mm);
λ – initial abstraction coefficients, sets as 0.05 (D´Asaro and Grillone, 2012);
Sr – maximum soil moisture retention, Sr=25400/CN-254, the CN is the curve number according to TR-55 manual (US Soil Conservation Service, 1986);

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METHODOLOGY
Rainfall-runoff model

Then, we can calculate the amount of infiltration and the surface runoff by Equation (4):

$$\mathbf{Q_P - Q_f = Q_r + Q_d = \sum_{n=1}^{N} A_n R_n} \quad (4)$$

where A_n – land area of the nth type land;
R_n – direct runoff caused by nth type land;

After obtaining the surface runoff, we can estimate the flooding area and inundation depth through ArcGIS 3D Analyst Tools.

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METHODOLOGY
Sponge city scenarios

There are multiple approaches to water treatment in the framework of the Sponge City strategy, including lamination, interception, filtration, infiltration, retention and storage, drain.

Therefore, it is possible to establish the following table for the sponge city strategies applicable to the City of Barcelona: (Medi Ambient i Serveis Urbans-Ecologia Urbana, 2017)

The practice of sponge city strategies can improve the infiltration capacity of land, but it also requires certain economic cost support.

Table 2. Sponge city strategies applicable to the City of Barcelona

	Volume reduction increase Cost increase →		
Retention		Water cisterns	Rain garden
Filtration	Vegetated strips	Green covers	
Infiltration		Permeable pavement	
Treatment	Vegetated ditches	Bioretention strips	Wetlands

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PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES
Specific Plan

We will propose the specific plan of the sponge city strategies from four aspects:

Building roof, Walking trail, Parking, and Open space. Different strategies mean different flooding mitigation effects and capital investment. Usually, the appropriate plan will be selected according to the actual situation of the region. (Figure 4)

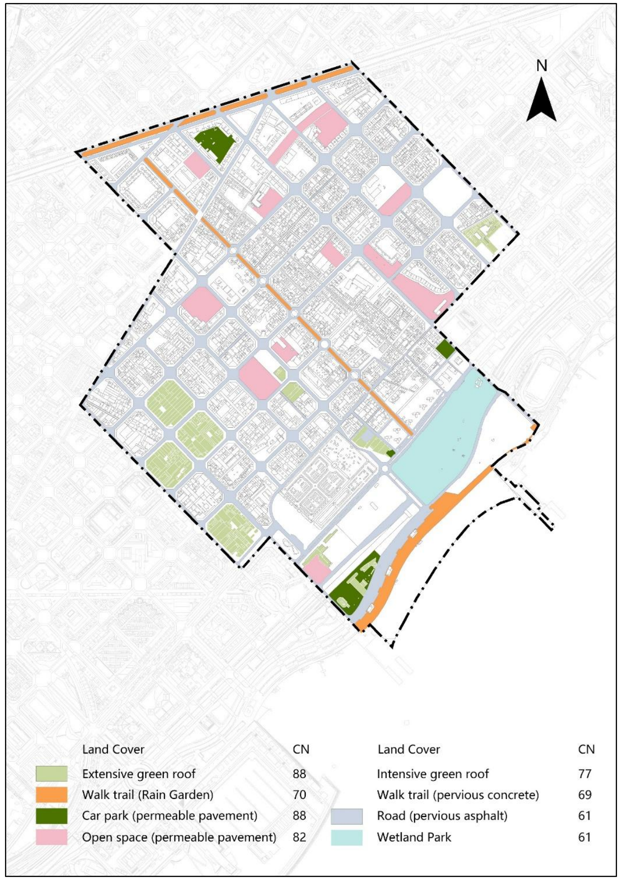

Figure 4. Plan of Sponge City Strategies.

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PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES

Specific Plan

Building roof

Due to the difficulty of obtaining consent from private owners to retrofit roofs, this study selected commercial and public buildings to build green roofs.

There are two types of green roofs, extensive green roofs are extensively treated and require very low maintenance once the vegetation has been consolidated. The Intensive green roof, on the other hand, has an intensive or semi-intensive plant finish that requires normal maintenance.

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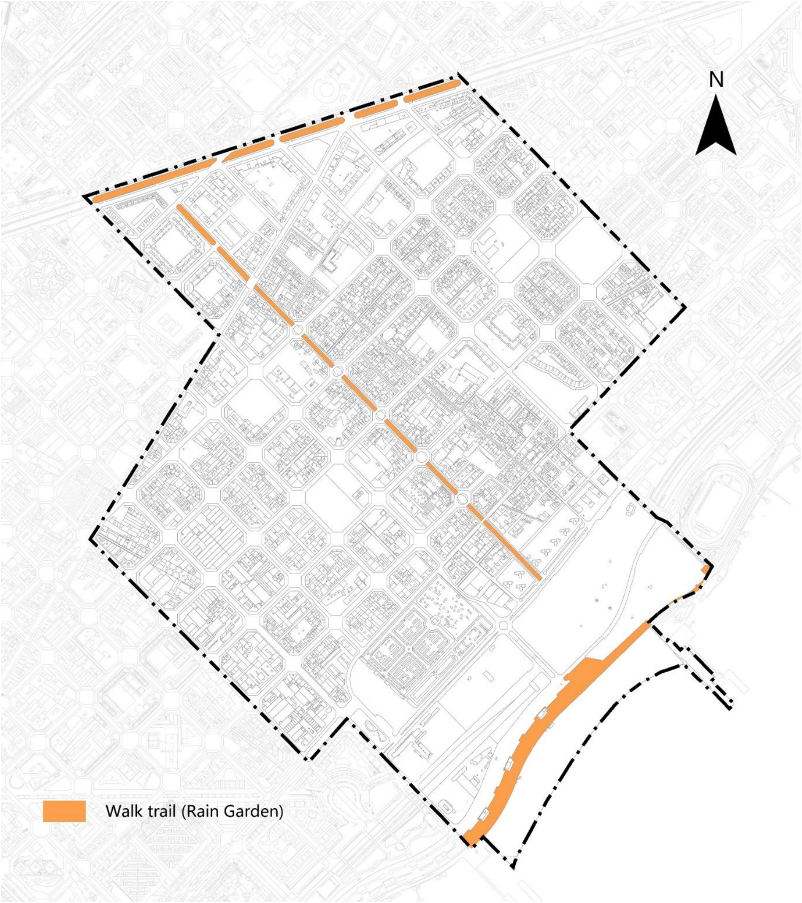
PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES

Specific Plan

Walking trail

El Poblenou has two main walking streets and a coastal promenade.

The use of rain gardens on the sidewalks can effectively absorb rainwater and become part of the landscape. It is planned to build a rain garden of 1 to 1.5 meters wide on both sides of the sidewalk, which is estimated to be 10% of the total sidewalk area. Another more effective way is to use the pervious concrete, but the cost is relatively high.



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PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES

Specific Plan

Parking

Most of the open-air public parking lots in El Poblenou are in poor condition, and it is planned to use permeable pavement in the car park, a common choice is turf stone paver filled with grass.

I also noticed that on-street parking occupies most of the road, and the original impervious pavement can be replaced with permeable asphalt, which is estimated to be 20% of the total road area.

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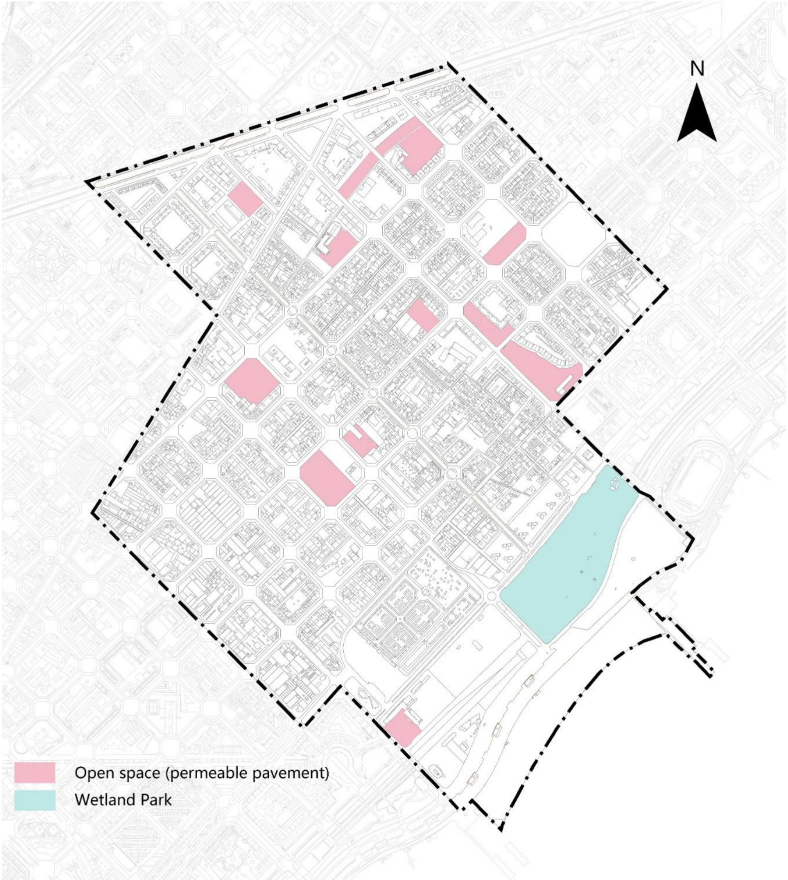
PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES

Specific Plan

Open Space

For parks and public spaces, we plan to increase permeable paving and plant cover.

In addition, the introduction of the wetland park into the coastal park of El Poblenou can effectively improve the urban landscape and adjust the urban microclimate while providing water storage functions.



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METHODOLOGY
Sponge city scenarios

In this study, we simulate two scenarios of sponge city strategies (Table 3).

In Scenario 1, we use the more economical sponge city strategies, while in Scenario 2, we use the sponge city strategies that can increase infiltration capacity more efficiently but at a higher cost. We will simulate urban flood events in these two scenarios and compare them with the current condition, so that different zonas can choose the better sponge city strategy scenario according to their own situation.

Table 3. Sponge city scenarios

	Scenario 1 (Low cost)	Scenario 2 (High Mitigation)
Building roof	Extensive green roof	Intensive green roof
Walking trail	Rain garden	Pervious concrete
Parking	Car Park (permeable pavement)	Street Parking (permeable asphalt)
Open space	Permeable pavement	Wetland Park

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PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES

Scenarios of sponge city strategies

As we can see in the Table 4, all two scenarios show their flooding mitigation effects from the proposed strategies.

In Scenario 1, the flooding volume is 53387.87 m3, around 8% less than the current condition, and the flooding area is reduced by 12%.

Scenario 2 shows slightly better flooding mitigation than Scenario 1, the flooding volume produced by Scenario 2 is 48723.20 m3, and the flooding area is 61514 m2, which means the influence of precipitation flood decreases by around 25%.

Table 4. Sponge city scenarios

	Infiltration Volume (m^3)	Runoff Volume (m^3)	Flooding Area (m^2)	Maximum Inundation Depth (m)
Current condition	20225.33	57899.77	80400	2.675
Scenario 1 (Low cost)	24737.24	53387.87	71248	2.615
Scenario 2 (High Mitigation)	29401.91	48723.20	61514	2.545

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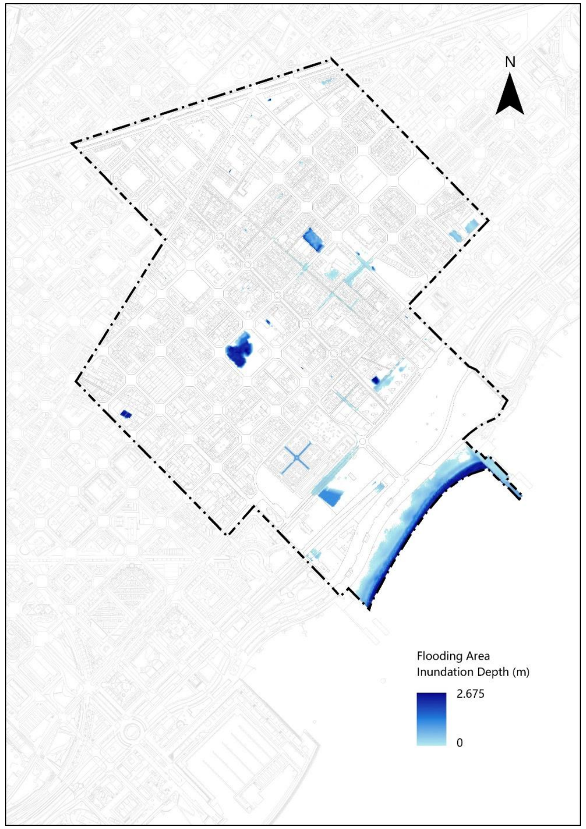
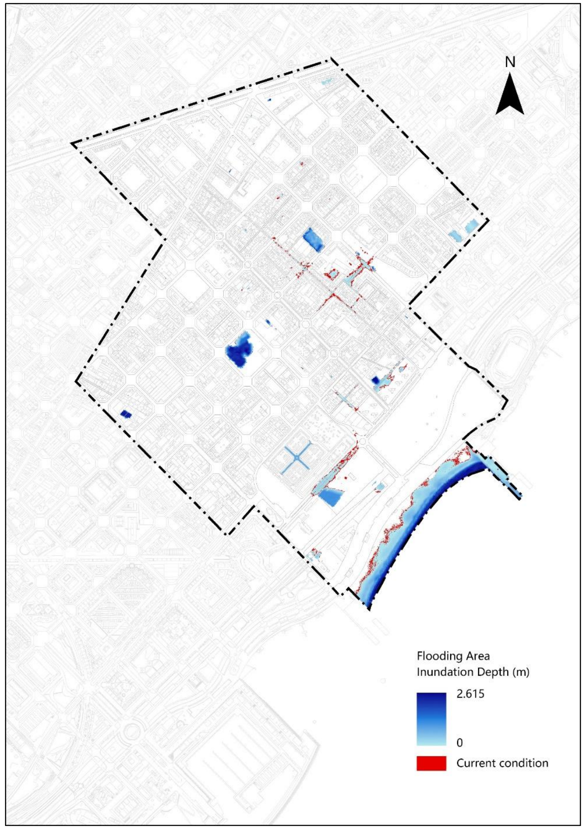
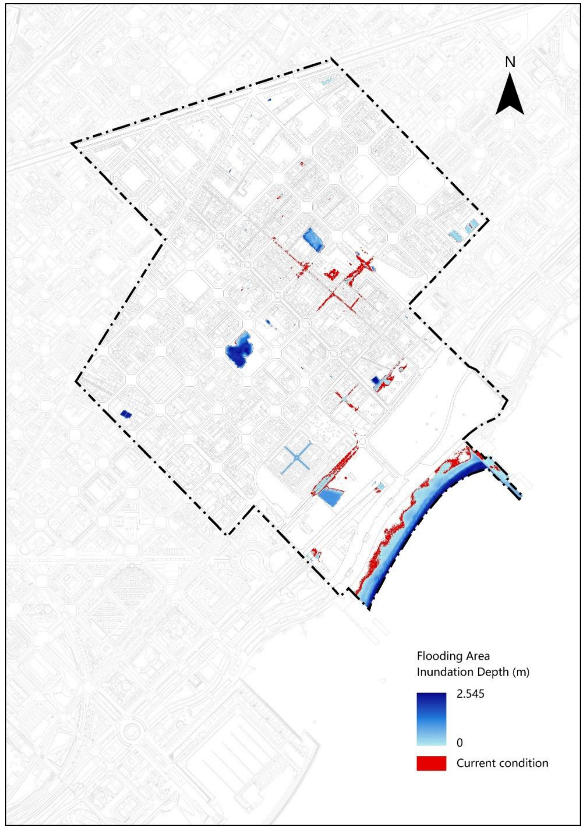
PRACTICE AND ANALYSIS OF SPONGE CITY STRATEGIES



Fugure 5. Flooding map (Current condition)



Fugure 6. Flooding map (Scenario 1)



Fugure 7. Flooding map (Scenario 2)

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CONCLUSIONS

Storms and floods have affected many cities around the world, not just coastal cities, but coastal cities are clearly under greater threat. Urban drainage systems have developed for a long time, and sponge city is the latest generation of sustainable and flexible urban drainage systems. Today, we have a lot of technology to obtain high-precision urban and weather data, and many tools to help process these data. Quantifying and visualizing flood assessments can provide a more intuitive view of the urban flooding mitigation effect of strategies. Through the comparison between the current condition and the two scenarios, **it can be seen that the sponge city strategy can effectively reduce the surface runoff and flood area, and the Scenario 2 with the high infiltration capacity significantly mitigates the urban flooding risk.**

However, we also noticed that the ability of infiltration of soil is limited, and the sponge city strategy will have a certain upper limit on the mitigation of surface runoff. It still cannot completely eliminate surface accumulation water, and the proposal with infiltration capacity means more capital cost. Therefore, we should choose the appropriate proposal and coordinate with other drainage strategies to obtain the maximum benefit.

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