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Sponge City: A Paradigm in Urban Flood Crisis Management

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Review Article

Abstract

INTRODUCTION: Sponge city, a fundamental strategy for solving water and environmental challenges, has attracted the attention of researchers around the world in recent years. Hence, the aim of this research is to examine the sponge city as a paradigm in urban flood crisis management.

METHODS: In this applied study, the research method is both descriptive and analytical. Data were collected from review articles, book chapters, grey literature, online pages, and newspaper articles. For qualitative content analysis, an inductive method was used, which combines data collection, extraction, and analysis, and gradually generates a discussion.

FINDINGS: According to the findings, the sponge city model involves comprehensive improvement of urban water resources and the aquatic environment in urban areas and a way to respond to water challenges and environmental degradation, promising to resolve environmental problems, increase welfare, growth and development, and achieve sustainability in societies. It emphasizes the integration of environmental considerations into all physical structures in urban spaces with the aim of harmonizing city development with the natural environment and advancing the principle of sustainability through the alignment of human and ecological processes in urban environments.

CONCLUSION: The results show that the sponge city and its principles can contribute to sustainable development in environmental, social and economic dimensions. A sponge city construction can improve the ability of cities to adapt to environmental changes and cope with floods, encouraging the development of cities towards a healthier and more sustainable direction.

Keywords: Sponge city; Flood; Urban drainage; Sustainable development.

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Introduction

In the recent years, more than half of the worlds' population is living in the urban areas and the cities are becoming increasingly dense. (1)

It has been projected that around 70% of the total population of the world would be living in the cities if the present growth of the cities continued by the end of 2050. (2)

Cities are mainly composed of impermeable surfaces and do not pay attention to the preservation of the environment and hydrological features. So that the destruction of many natural habitats and hydrological systems and changes in the process of material and energy cycles, etc. are part of the fundamental challenges in cities. On the average, disasters related to weather, climate and water hazards have occurred every day over the past 50 years, during which climate change is responsible for about $202 million and 115 deaths daily, according to the World Meteorological Organization. (3)

Among natural hazards, floods are the third leading cause of casualties, resulting in nearly 60,000 deaths in the past 50 years. (4) Water management is a vital issue in sustainable urban development. Improper water management in cities leads to waterlogging and flood formation, urban water scarcity, soil erosion, rainwater waste, and water bodies' pollution. (5)

Insufficient control of urban floods also causes social problems, such as the spread of infectious diseases and homelessness or death of human beings. (6)

Restrictions on the design of sewers and drains and improper design of urban structures have led to

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pluvial flooding in many countries. (7-10) Urban flooding, seen as a natural disaster, ensues when rainfall cannot quickly and adequately be drained through drainage channels and other water bodies. (11) There is an increase in impervious surface area, runoff, and flood recurrence rate. (12) Today, flooding has become a serious disaster around the world, including the US, Europe, South East Asia, and Africa. Some countries have become very vulnerable to flooding mainly because of their geographic location and climatic conditions. India is the most flood-susceptible country globally and accounts for one-fifth of global deaths by flooding. (13)

The core reasons for flooding in India are high-intensity rainfall in a short period, poor and inadequate drainage capacity of rivers and failure of flood control structures. (14) China has also suffered severe water problems, including water scarcity (15), flooding, and water pollution. Flooding risk is a more serious water security issue in China, several studies show nearly 98% of China's 654 leading cities have problems with flooding and waterlogging because of the rapid growth in recent years creating urban sprawls that enclosed floodplains with waterproof concrete. (11)

In 2013, to solve the serious urban water environment problems, the Chinese government put forward the sponge city strategy, which is an urban storm water management system that enables the city to absorb and save the storm water like a sponge and release the reserved water for use when the city is short of water, so that the sponge city can play an important role in the sustainable development of cities. (16)

Theories of city such as ecological city, low-carbon city and smart city have been established for the purpose of achieving the coordination and unity between ecological environment and social and economic development, which provide reference for sponge city. In terms of urban storm water management, foreign advanced experience has also played a positive role in the proposal of sponge cities in China and sponge city adds the Chinese style urban storm water management concept into the worldwide urban storm water management system. (11)

The concept of sponge city is a holistic approach in planning, construction and management of urban water resources for more resilient ecological and drainage infrastructures. The sponge city guidelines, proposed by Chinese researchers in the early 2010s, have been integrated into urban development policies by the Chinese government since 2014. (17) Similar ecological models include the low impact developments in the United States, the sustainable urban drainage systems in the United Kingdom, the water sensitive urban design in Australia and the low impact urban design and development in New Zealand. (18) The unique aspect of the Chinese concept of the sponge city is to manage storm water in a sponge like manner by absorbing, storing and purifying water in soils, lakes and vegetation (Fig. 1). Sponge city is capable of restoring urban ecologies and rebuilding urban hydrological systems. (19)

A sponge city integrates natural ecological resources and built infrastructure into a resilient stormwater management system. (20) Unlike traditional pipeline-based drainage systems, sponge city management offers residents many benefits, such as eliminating flooding at the source, reducing pollution from runoff, conserving freshwater, reducing the urban heat island effect by cooling vegetation, and providing aesthetic value. The sponge city is a new concept in urban water management and a low-impact development model that comprehensively considers water resources, the aquatic environment, water ecology, water safety, and water culture. It represents a new approach to urban construction that helps cities adapt to environmental changes, makes them resilient, and enables them to cope with the consequences of storm disasters. (21)

Sponge city construction can reduce natural disasters caused by rainfall, for example; during the rainy season, flooding and inundation occur more frequently in southern cities, while building sponge cities can effectively reduce the urban heat island effect, control urban water pollution, reduce dust and noise in urban air, and provide sufficient space for urban development in tropical monsoon climates. The construction work of the sponge city in China is based on Marx's ecological philosophy, which has been enriched and developed in practice. In this city, the collected rainwater can be used for cleaning roads, green irrigation and daily water supply for residents. In the new urban sewage treatment plant, the treated water can also be used for cleaning roads, green irrigation and daily water consumption for residents. It will also bring certain social effects, such as expanding green space and improving the city's environmental environment, and increasing new job opportunities. In the construction of sponge city, the concept of green

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environment protection is greatly promoted and a low-carbon lifestyle is integrated with the city (22).

The collected rainwater can be used for road cleaning, greening and irrigation and domestic water for residents, thereby improving the ecological quality of the city. In fact, after the construction of sponge cities, the urban green areas are greatly improved and the ecological environment of cities is greatly enriched. Accordingly, in the construction of sponge cities, the pollution situation of the river should be considered and low-impact measures and a more scientific approach to greening should be taken to maximize the performance of the river system. In addition, a series of rainwater infiltration measures have been adopted, which on the one hand replenishes groundwater and rich water resources, and on the other hand, by cutting off rainwater infiltration, the convergence of rainwater is reduced and all rainwater is concentrated within the area of the rainwater measures, which reduces runoff and controls flooding in the city.

As mentioned earlier, the sponge city is a new urban planning model in China that emphasizes flood management through strengthening green infrastructure rather than relying on drainage systems, a proposal made by Chinese researchers and adopted by the Chinese Communist Party (CCP) and the State Council as a nationwide urban construction policy in 2014. The concept of sponge city is that urban flooding, water shortage, and heat island effect can be can be reduced by having more urban parks, gardens, green spaces, wetlands, natural strips and permeable pavements that both improve environmental biodiversity for urban wildlife and reduce flash floods by serving as a reservoir for capturing, retaining, and absorbing excess storm water. Harvested rainwater can be repurposed for irrigation and treated for home use if needed. It is a form of a sustainable drainage system on an urban scale and beyond. Sponge city policies are a set of nature-based solutions that use natural landscapes to catch, store and clean water; the concept has been inspired by ancient wisdom of adaptation to climate challenges, particularly in the monsoon regions in southeastern China. According to Chinese authorities, sponge cities are part of a worldwide movement that goes by various names: 'green infrastructure' in Europe, 'low-impact development' in the United States, 'water-sensitive urban design' in Australia, 'natural infrastructure' in Peru, 'nature-based solutions' in Canada. In contrast to industrial management, in which people confine water with levees, channels and asphalt and rush it off the land as quickly as possible, these newer approaches seek to restore water's natural tendency to linger in places like wetlands and floodplains.

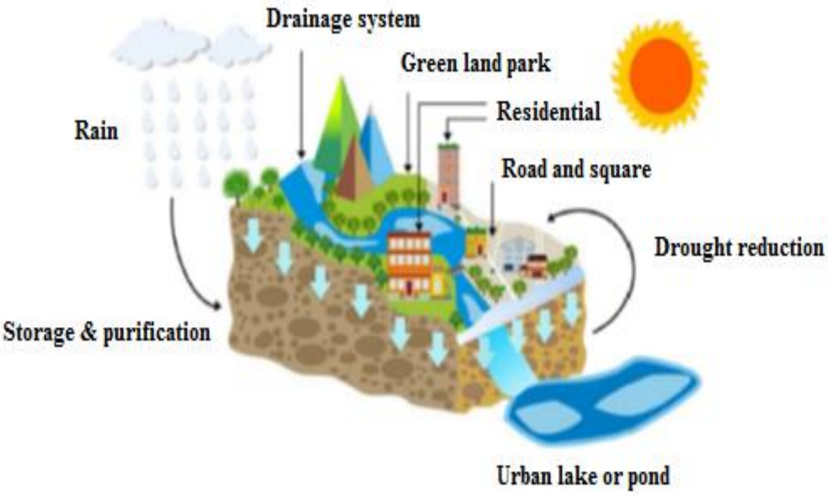

Fig. 1. Water cycle in a sponge city (17)

Ma et al (2023) in their study concluded that the overall planning of China's current policies in sponge city construction and the specific analyses conducted by experts from both subjective and objective aspects have not been able to completely fill the gap in this regard, thus making it particularly urgent to conduct in-depth studies. Based on this, this paper discusses the performance assessment of sponge cities in China on the basis of the prediction and analysis of the development trend of sponge cities in China. In the performance assessment system, the correctness and timeliness

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of the index system should be considered in terms of practical effects; in the city performance assessment, the ideas of new city development such as low-carbon cities and smart cities should be combined to build a comprehensive and multi-perspective intelligent assessment system, so as to provide a strong boost to promote the development of city construction and its evaluative research. Firstly, a system-dynamic model is applied to sort out and combine its internal operation mechanism, and a set of evaluation systems based on the ecological philosophical perspective of the sponge city and urban sustainable development performance is established. Second, to improve the accuracy of the research results, parallelism tests and robustness analysis were conducted on this performance index evaluation system. The study's results show that sponge city construction has achieved good results in sustainable urban development and has contributed to future development. (22)

Tang et al (2020) stated in their study that in sponge city construction, it is important to consider all aspects and reform priorities to provide legal basis and economic support for its development, and it should also make full use of resources in government decision-making, law, design engineering systems, and public participation to play an important role in sponge cities. (23)

Koster (2021) in his paper concluded that innovative engineered solutions for a sponge-based rainwater harvesting are the key to an adaptive and flexible water supply infrastructure for Sponge Cities especially to preserve its manifold urban water and life quality services. The complementary water service emerged from the Sponge City, can provide an imperative contribution to compensate the high capital investments and to cover the operation and maintenance costs. This enables a tremendous funding opportunities that can be invested for the preservation of the blue-green future city. Moreover, this would offer a feasible way of urban water service development over the negative impacts caused by climate change. (24)

Yin et al (2021) stated in their study that Sponge City Construction (SPCC) process (planning, design and construction) as well as the assessment of SPC, including operation, maintenance, and effectiveness. The paper offers some tactics including a) In the planning and construction stage of SPC, the goals and systematic plans should be formulated according to local water-environmental conditions. The drainage plan should cover the strategy to dispose runoff volumes at sources and the ultimately goal for flood mitigation. Its design involves the combination of various green and grey infrastructures; b) It is important to identify monitoring methods and hydrological models which can be used to assess the performance of a SPC. With adequate field data, all models and methods should be calibrated for not only runoff quantity and quality control but also the alleviation of urban heat island effects, including the base flows and local groundwater table; c) Based on the regional field data, it is necessary to standardize regional design parameters, construction material specifics, and maintenance scheme and schedule that would significantly affect the facility's infiltrating and filtering processes, therefore, a regular maintenance program should be initiated to monitor the operations of the as-built facilities according to local climate conditions. The paper evaluated several maintenance methods for ten typical facilities to provide a reference for the operation and maintenance of facilities in SPCC. (25)

Noori and Rezaei (2023) stated in their study that the final leveling model of the functional dimensions of the sponge city consists of four levels, which has rainwater management and the implementation of green-blue infrastructure at the lowest level and the role of the underlying stone of the model. Rain with the amount of 3.342 and 2.435 has the most influence and improvement of urban ecosystems and biodiversity with the value of 2.541 has the most influence. Also based on index (D+R); the implementation of green-blue infrastructure with a value of 5.639 has the most interaction with other dimensions, but according to the (D-R) index; the implementation of green-blue infrastructure, rainwater management and flood protection and risk management are considered as causal variables, and the other four dimensions with a negative value are considered as effect variables. Therefore, the implementation of the sponge city concept can be placed on the agenda of urban planners of Shiraz as a practical way to achieve a healthy and sustainable urban system. (26)

Song (2022) stated in his study that it is increasingly vital to prioritize the protection of natural water resources during urban planning and development. China has advanced the concept of Low-Impact Development (LID) through the establishment of sponge cities. Numerous LID

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approaches have been utilized in urban building and renovation, including rain gardens, green roofs, and permeable pavements. The purpose of this paper is utilized the keyword retrieval method to review the existing literature on three sponge city technologies, with an emphasis on their performance, adoption/implementation in China, and identify the knowledge gaps and limitations. Rain gardens reduce surface runoff by 25–69% and peak runoff by 12–71%. Green roof can reduce the rate of rainfall-induced surface runoff with a maximum delay time of 20 min. Permeable pavements reduce spalling, cracking, and uneven settlement; use construction waste as a construction material for sustainable development. Besides, the areas of inquiry for researchers and possible recommendations to urban planners are also provided. Thus, based on this review, it is recommended that a better understanding of the adaptive capabilities of sponge city technologies could result in more feasible options for sponge city planning, design, development, and implementation. (27)

Rostami et al (2024) concluded in their study that the main aim of this research is to optimize water allocation, store water resulting from rainfall, and reduce flooding. Considering the increase in population, these problems and challenges are becoming more apparent. Therefore, in this study, using the concept of a sponge city, flood-prone areas of Sanandaj city were identified, and the necessary steps, preliminary studies, and research for implementing this concept were carried out. Based on this, in this research, the topographic status of the area under study was investigated using Digital Elevation Model (DEM), and then, water catchment areas and low-lying areas were identified using GIS software. Subsequently, the infiltration rate of water in the soil of Sanandaj city for different soil types was calculated, and the amount of precipitation was estimated. Using the NDVI map and land use map, buildings and roads were determined by QGIS software, and the Curve Number (CN) was calculated along with the volume of runoff resulting from rainfall. Furthermore, the amount of runoff obtained from precipitation in 2021 in the urban area has been allocated to various urban, industrial, and agricultural uses using the WEAP model. (28)

Methods

In this applied study, the research method is both descriptive and analytical. Data were collected from review articles, book chapters, grey literature, online pages, and newspaper articles. For qualitative content analysis, an inductive method was used, which combines data collection, extraction, and analysis, and gradually generates a discussion.

Findings

Key characteristics of sponge cities

a) Limiting impermeable surfaces in the city;
b) A significant share of hydro-engineering solutions and the simulation of natural system including blue green infrastructure to increase the porosity of the urban fabric;
c) The use of vertical and horizontal storm water storage and infiltration systems;
d) The use of drainage system that allow water to in filter and be absorbed into the soil;
e) Rain water recycling using lot-based monitoring system;
f) Introducing two or three cycle use divided into drinking water, water used for urban vegetation, and water used for urban sanitary purposes (for flushing toilets and washing streets);
g) Maintaining a diverse topography which improves water retention properties and allows the use of solutions including blue- green infrastructure;
h) Introducing buffer zone around built-up areas allowing rainwater to infiltrate into ground;
i) Maintaining the community of interconnected waterways, canals, streams, and ponds in districts that help to filter and retain water;
j) Maintaining the continuity of green areas;
k) Protecting and creating urban ecosystems by increasing their biodiversity;
l) Educational campaigns encouraging residents to save water.

The planning framework and underlying principles

At the heart of the sponge city concept are several important principles: Permeable Surfaces. Sponge cities incorporate permeable pavements, green roofs, and other porous materials to allow rainwater to infiltrate the ground instead of running off into storm drains. The planning framework used Sponge City program is based on three general principles which have been derived from water management practices developed in the

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Netherlands. This framework is used in the selection, final design and engineering of the interventions of the program. These principles are:

1.Interventions should mimic natural processes as much as possible. By introducing Blue and Green Infrastructure (BGI), the capacity of the city to deal with water stress such as drought, flood and water pollution will increase. BGI can also provide important additional ecosystem services and socio-cultural benefits and enhance the adaptability of the water system to future (uncertain) changes in climate and land use.

2. Interventions should foster or contribute to the preservation or restoration of the indigenous (man-made) water system. In many cases these systems do not exist anymore in modern cities as the huge demand for land has resulted in landfilling of indigenous canals and detention ponds to allow these landfilled areas to be used for urban development. These indigenous water systems have evolved over many decades and even centuries. They function well and sustainably under the prevailing (slow changing) geophysical and climatological conditions. In this context the indigenous water system refers to the polder water system before urbanization and offers important directions to better manage current water challenges.

3. Interventions should contribute to the overall performance of the city. Hence, these interventions should not be conceived as isolated, ad hoc interventions, but as ones that are interacting and impacting the urban water system as a whole. Applying this principle to manage storm water sustainably results in an intervention which is not shifting its problem to a neighboring area. Adopting this principle requires a strategic, integrated approach at the city-scale and is based on an understanding of the function of the water system. The last two principles are also reflected in the so called "Layer Approach," used in landscape planning and management. The Layer Approach provides guidance to identify, select, prioritize, plan and design interventions based on their impact on the water system and on the opportunities of an intervention arising from the dynamics (end-of-life cycle) of and interdependencies (incl. synergies) among the various components of the urban landscape. These components consist of: (i) surface and subsurface infrastructure;(ii) other engineered elements of the urban fabric such as buildings and public spaces; and (iii) the top and deeper soil layer; and (iv) the natural water system. (11)

The benefits of Sponge Cities

1) *Flood Mitigation*: One of the primary benefits for the development of sponge cities is flood mitigation. Urban areas with vast expanses of concrete and limited green spaces often struggle to absorb excess rainwater. This leads to flash floods and overwhelmed drainage systems. Sponge cities incorporate permeable pavements, green roofs, and retention ponds to absorb rainwater, reducing the risk of flooding.

2) *Water Resource Management*: Sponge cities focus on reusing rainwater as a valuable resource. By collecting and treating rainwater, these cities can reduce their dependence on dwindling freshwater sources. This practice also lessens the strain on water treatment facilities and decreases the likelihood of water shortages during droughts.

3) *Improving Water Quality*: Traditional urban surfaces like roads and parking lots contribute to water pollution by allowing contaminants to flow directly into water bodies. Sponge cities, with their green infrastructure and filtration systems, help improve water quality by trapping and treating pollutants before they reach rivers and lakes.

4) *Enhancing Urban Greenery*: Sponge cities emphasize the importance of green spaces, which provide multiple benefits. They reduce the urban heat island effect, enhance biodiversity, and promote overall well-being among residents.

5) *Resilience to Climate Change*: With climate change leading to more frequent and severe weather events, including heavy rainfall and storms, sponge cities are better equipped to adapt. They can absorb excess water and withstand extreme weather conditions, making them more resilient in the face of climate-related challenges.

6) *Economic Benefits*: Sponge cities can lead to cost savings in the long run. By reducing flood damage, lowering water treatment costs, and creating green jobs, these cities contribute to economic stability and sustainability.

Design Features of Sponge Cities

Urban areas with hard surfaces are liable to suffer from excessive water pooling or flooding at some cases. Drainage systems and flood barriers are sometimes sufficient, but at many other cases are overwhelmed especially with unstable climatic conditions and maintenance deficiency. Therefore, Sponge cities are designed on the basis of blending hard concrete surfaces with soft permeable water

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bearing surfaces; it depends on promoting roads and bridges along with developing water resource and landscape architecture planning.

Main crucial design features for sponge cities include the following:

1) *Contiguous porous green surfaces* presented by a network of adjacent green spaces that are linked together through water channels, lakes etc., designed to naturally hold-up, filter and treat water across urban city spaces.

2) *Green rooftops and green facades* acting as a buffer layer for rainwater, absorbing and filtering it before being released to water recycling networks.

3) *Porous city design elements*. It designs porous roads, pavements, and porous hardscape; with higher-than-normal air voids to allow water to pass and penetrate the hard surface and once again rechargeable. Recent studies don't recommend porous paving for areas with high-speed traffic nor areas with higher levels of pollutants since it is considered a lower load-bearing technique and water sources couldn’t be treated before infiltration. However, it's appropriate for dense cities for it doesn’t need additional spaces. (29)

4) *Retention lakes and tanks*. The existence of a series of various-sized lakes, ponds or water features to receive and collect filtered water through drains and channels coming from rainfall and water runoff. These tanks or containers are designed to hold water permanently to be stored for later use, and also helps reduce evaporation that occurs in the soil at the banks of the lakes. Cities and many urban areas are likely to use or design underground water tanks, whereas many rural areas prefer to install lakes for agriculture use.

5) *Constructed wetlands*. A recent effective technology for waste-water treatment applied within urban areas, and mainly characterized by shallow water depth and slow flow of water that result in long time retention. These kinds of wetlands purify wastewater by degradation and sorption, stores rainfall and other water runoff sources and operate systems for recycling nutrients. In addition, constructed wetlands are designed to accommodate recreational, cultural and educational facilities. (30)

6) *Programs for water recycling and savings*. Systems are planned aiming to maximize water savings; they depend on the amount required for storage and the availability of space to store.

Fig 2. Sponge city model

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Fig 3. Green space in the sponge city

Fig 4. Design of buildings in sponge city

Green space design

The green space of park is a land for afforestation, which is open to the public for recreation in the city as its main function, and in which there are some recreational facilities and service facilities, and which can protect the ecological environment and beautify the landscape and prevent and mitigate natural disasters. Urban park green space plays an active and indispensable role in alleviating the current urban environment problems and protecting urban ecology. It not only takes on the function of protecting and improving urban ecological environment, but also afforests and beautifies the urban environment to provide citizens a comfortable casual activity space. It is an important part of urban construction land, urban green land system and urban public facilities. (31)

In the process of landscape engineering design and planning, the back-and-forth change of design is a big taboo in the whole design process. When designing and planning the green space based on sponge theory, pay attention should be to the efficient and reasonable use of the geographical location of the garden, and consider as many difficulties as possible before the design. If there is low-lying land in the construction of green spaces, it can be fully utilized as a drainage area or reservoir. In the actual operation process, the

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designer cannot blindly design, to specific problems specific analysis, in the actual operation to different types of garden plants for reference, according to the water pit to carry out scientific planning and design. The design and application of green space is different from that of buildings and other design and application. (32)

In the design and planning of green space, it is necessary to clearly grasp the specific distribution of groundwater outlets and pipeline network, take this important data as a reference, combine it with the design scheme, and ensure the rationality of low-lying land water flow to the planning. This is also an important measure to improve the drainage effect of garden green space. The construction of green space can not only provide better ornamental for the garden, but also provide more lessons for many plants. For example, the root microorganism of some plants has a very good decontamination effect, which can help the city to be more environmentally friendly and clean in the process of urbanization. Therefore, in the actual process of sponge city, through the above theoretical research results, the plants can be reasonably selected and configured What can better maximize is that green space can play its due purification effect. (32)

Design of buildings

As cities develop, miles of impervious pavement are laid over forest or wetlands, displacing the natural flood management systems like creeks, underground streams, or bogs. In a completely uninhabited landscape, rainfall integrates into the natural water cycle by four different ways: it soaks all the way to the ground and becomes groundwater; runs down valleys into bodies of water and finds its way to the sea; is taken up by plants; or just evaporates. In urban or suburban sprawls with paved roads, highways, and parking lots, water has nowhere to go, so every heavy rain can turn into a flood. In an era marked by rapid urbanization and climate change, the concept of "sponge cities" has emerged as a compelling solution to address the myriad challenges facing urban areas worldwide. These innovative urban designs prioritize sustainable water management to enhance resilience, mitigate flooding, and promote environmental sustainability. The application of sponge city theory in landscape architecture planning should focus on its sponge nature, and pay attention to the rationality of layout In order to achieve this, it is necessary to systematically understand the terrain where the building is located. No matter what kind of landscape design is based on the terrain where the building is located, it is necessary to sort out the terrain characteristics and relevant data into the necessary building data for reference in the garden forest design, so as to continuously improve the perfection of rainwater collection system construction. In general, when designing buildings, we should take into account the different characteristics of rainy season and non-rainy season, and design buildings according to different urban precipitation. For example, in rainy season, the urban precipitation is relatively sufficient, especially in some southern cities. After the southern cities enter summer, the precipitation is sufficient. In these areas, more hidden channels can be designed to Rainwater collection, the so-called hidden channel, is the design of water channel in some inconspicuous places of the building. The main function of the hidden channel is to collect rainwater. (32)

After rainwater is collected in the hidden channel, it flows into the filter tank, and then puts gravel and other materials into the filter tank. Through this method, the preliminary filtration of rainwater is completed. It is necessary to know the impurities and microorganisms of rainwater before filtration very much, it is difficult to use directly. In the sponge city theory, it is necessary to make full use of the rainwater resources to form the infiltration mode to carry out the daily use of some enterprises and families, so it is necessary to filter the rainwater. Through the preliminary filtration of rainwater, most of the impurities in the rainwater are filtered. In this case, rainwater can be used in the construction of the city. Generally speaking, the filtered rainwater will be connected with the reservoir, which provides sufficient water for irrigation plants.

There is no fixed installation location of rainwater collection devices. In some buildings, rainwater collection devices will be placed on the top of the building, which is also a reflection of sponge theory. Installing the rainwater follow-up device on the top of the building can permeate the collected rainwater downward. In the process of infiltration, it will gradually enter the water storage pipeline and collect with the participants in the Garden Road, and then flow into low-lying places such as green space. The road design also should be based on the geomorphic characteristics of the area, respect the actual situation, and make

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reasonable planning for the road. As far as the practical process is concerned, the ring road network can be designed. Different from the traditional road planning mode, the use of mesh design can make different road elements interpenetrate among them, making the road more practical and better drainage performance. Therefore, in road design, the use of mesh design is most in line with the sponge city construction theory.

Challenges of implementation the sponge city program

Government think tanks, experts, and media have identified the key challenges to successfully implement sponge cities, mainly related to the following three concerns:

1. *Low priority for sponge city and climate change adaptation planning and investments*. Despite increased severity and frequency of extreme weather events, local governments' priority has shifted from climate change adaptation and developing sponge cities to other investment areas, perhaps reflecting a trickling down of national policy priority shifts in recent years.

2. *Fragmented investments and lack of citywide systematic and systemic implementation*. Investments in the pilot sponge cities are mostly small and fragmented without systematic and systemic analysis, planning, and investment prioritization. In some of the sponge city pilots, flooding occurred as before or even worsened, leaving the perception that the concept failed. After a devastating flood disaster in Zhengzhou in July 2021, many questioned the sponge city concept. It is important to consider that sponge city infrastructure coverage is far from sufficient to significantly reduce the risk of urban flooding in a city as a whole, and a lot more systematic planning, investment, and implementation is needed.

3. *Lack of integration across sectors and departments*. Effective coordination across concerned local administrative departments or bureaus and connecting related experts is essential for adaptation work. The analysis, planning, investment prioritization, and construction of sponge city green infrastructure need close coordination that must be continued during operation and maintenance once completed. (33)

4. *Challenges accompany sponge city from design to execution to maintenance phase*. The barriers are social, institutional, and political, rather than technical. (34)

To gain stakeholder support for relevant policies, it is crucial to demonstrate that Sponge City can bring greater economic and social benefits. Determining the challenges and barriers that Sponge City faces will help significantly improve the quality of implementation and increase efficiency. A good understanding of the Sponge City process will help the engaged community identify those challenges and barriers and plan to overcome them. (35)

Planning and Design

Designing and planning sponge cities require interdisciplinary collaboration between urban planners, landscape architects, engineers, and ecologists. Ensuring the integration of green infrastructure into the built environment requires careful coordination and creative solutions. Public Awareness and Engagement: Engaging local communities in the planning and implementation of sponge city projects is crucial for their success. Building public awareness of the benefits of green infrastructure and fostering a sense of ownership among residents can help to ensure the long-term sustainability of these initiatives.

Discussion and Conclusion

Overexploitation of natural resources and the environment during urban development has led to numerous environmental challenges in cities. Most cities face environmental problems such as frequent flooding, runoff pollution, waste of rainwater, and ecological damage as a result of urbanization because traditional urban construction has disrupted the natural cycle of rainfall. Rapid urbanization, unplanned urban development, and recent climate changes have had detrimental effects on human settlements and the environment. Consequently, adoption of environmental technologies to achieve a balance between environmental protection and mitigation of the adverse impacts of development has gained significant global importance in creating sustainable societies.

An Integrated Urban Water Management strategy, called sponge city, has been developed to address the aforementioned issues in urban development. The sponge city model involves the comprehensive improvement of urban water resources and the water environment in urban areas.

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In response to water challenges and environmental degradation, the concept of the sponge city initially proposed in China holds promise in addressing environmental issues, enhancing human well-being, fostering growth and development, and achieving sustainability within communities. It emphasizes the integration of environmental considerations into all physical structures within urban spaces, aiming to harmonize city development with the natural environment and advance the principle of sustainability by aligning human and ecological processes in urban settings.

China's sponge city initiatives demonstrate an alternative strategy to tackle water shortage and flooding issues faced by many cities today under a changing climate. By integrating nature's green infrastructure into urban storm water management systems, the sponge city model utilizes nature's own capacity in absorbing, storing, and purifying rainwater infiltrates and runoffs, offering a more holistic and resilient approach to manage runoffs, pollution and water resources in urban environments when compared with traditional pipe and channel drainage systems, the 'gray infrastructure'. In many countries and regions, including China and India, the latter has been challenged by extreme rainfall events and floods in recent years. It also restores the ecological functions of the urban natural environment by storing and purifying runoffs while improving its landscape and aesthetics.

Like other low-impact development concepts, the sponge city model offers a smart and sustainable approach by integrating the power of nature in the urban water cycle, instead of relying solely on engineering systems and gray infrastructure.

Ethical Considerations

This article is a review study without participants.

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Author's Contributions

None

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Conflict of Interests

None

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