Symbiotic Street Landscape Design under the Sponge City Concept

Abstract

This study investigates symbiotic street landscape design within the context of China's sponge city framework and reveals how integrated methods of urban water management can tackle environmental issues while improving urban life in public spaces. This work focuses on a case study of Shanghai Lingang New City and systematically integrates rain gardens, permeable paving, and microclimate design to create street landscapes that meet ecological, hydrological, and social needs simultaneously. Results show that well-designed symbiotic street systems are capable of managing 75% of onsite rainfall, increasing biodiversity, ambient temperatures by 6-8°C, and greatly improving public space utilisation. Identifying success factors such as inclusive policy instruments, multidisciplinary approaches, and ongoing evaluation highlighted the refineable obstacles of complicated maintenance and perceived high cost of implementation. Such findings offer considerable insights for urban designers, landscape architects, and planners aimed at reframing street infrastructure into adaptive, multifunctional components of city systems designed for resilient urban environments.

Keywords: sponge city; symbiotic landscape design; rain gardens; permeable paving; urban microclimate

1 Introduction

Both developing and developed urban regions across the globe are increasingly having to deal with climate change challenges such as extreme weather, environmental degradation, and drought. In response, China has pioneered the "sponge city" concept: a comprehensive water management approach that seeks to increase the potential of cities to absorb, store, and purify rainwater while reducing flooding. As Ma et al. point out, it is not only a technical solution but rather a fundamental shift in mentality towards ecological urbanism and sustainable urban development [1]. The initiative is now at the heart of China's urban environmental policy aiming at remediation of problems arising from traditional grey infrastructure and shifting towards integrated nature-based solutions that operate with the natural hydrological cycle.

Along with buildings, street landscapes account for a large share of external urban public space. Streets are essential for the reception of sponge city concepts. They are linear spaces which historically favoured traffic but today increasingly fulfil multifunctional roles that span from social to environmental and aesthetic functions. The addition of rain gardens, permeable stone, and climate micro zones in street landscapes can provide a high degree of synergy between urban landscape elements and the natural systems. Chen's research on the design of wetland parks demonstrates

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such interventions can improve urban spaces and transform them into ecological assets while enhancing the public experience [2].
The Pearl River Delta region works as a "laboratory" for sponge city developments, as multiple municipalities have documented case specific approaches for implementation. As Feng et al. note, Dongguan's Dalang Town has pioneered integrated approaches to sponge infrastructure within the dense urban fabric – indicative of the adaptability of these concepts to varying urban morphologies. Huang et al. were able to identify these advancements yet Chikhi et al. were able to note ongoing gaps in developing strategic models which systemically meet the multi-faceted needs for implementation [3, 4].
The definition of symbiosis as mutualistic associations of two different organisms or systems provides insight into how landscapes of streets as a unit can serve hydrological, ecological, and social functions parallel to one another. Wang studied the application of landscape architecture in relation to dual-carbon technologies noting that interdependencies between the constructed and natural ecosystems improve sustainability objectives. Moreover, Huang et al. explain how pervious concrete pavements are essential to the dynamic process of sponge cities enabling the microclimatic regulation of urban spaces by water infiltration and evapotranspiration [5, 6]. The aspects of plant selection and biodiversity consideration are fundamental to the effective design of a rain garden. Shi et al. reviewed the issue of herbaceous plant biodiversity in Chinese rain gardens and stressed the necessity of choosing plants which aid local ecosystems and can survive in fluctuating moisture conditions [9]. From an ecological focus, Ding et al. argue for the optimisation of urban wildlife habitat networks toward urban-natural symbiosis and highlight the role of linked green infrastructure systems for sustaining ecological diversity [10].
This study addresses the application of symbiotic street landscape design in the case of Shanghai's Lingang New City, focusing on how the integration of rain gardens, permeable paving, and microclimate design geared toward sponge city principles can improve the quality of public space. Using Gören's idea of "urban symbiosis" [7], this research aims to formulate a holistic approach to street landscape design as ecological infrastructure that supports vibrant and comfortable public spaces. In addition, the research advances the application of constructed wetland technology principles within the framework of Cai et al.'s work [8] specifically into linear street landscapes within the densely built urban fabric of Shanghai's developing districts.

2 Theoretical Foundations and Contextual Background

The sponge city concept represents a paradigm shift in urban water management, placing additional emphasis on the imitation of natural hydrological systems in construction-dominated landscapes.While this approach has gained global recognition under various terms—including Water Sensitive Urban Design (WSUD) in Australia, Low Impact Development (LID) in North America, and Sustainable Urban Drainage Systems (SUDS) in Europe—China's sponge city initiative has distinguished itself through unprecedented scale and governmental commitment. The conceptual foundations rest on three interconnected principles: water retention, purification, and reuse, with the ultimate goal of creating cities that function as ecological "sponges"

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that absorb, clean, and utilize rainwater rather than channeling it away through conventional drainage systems.The theoretical framework for symbiotic street landscape design integrates ecological urbanism with landscape urbanism approaches, emphasizing the multifunctionality of urban infrastructure. As illustrated in Figure 1, this framework positions street landscapes at the intersection of three primary components—rain gardens, permeable paving, and microclimate design—each contributing to ecological, hydrological, and social functions. This integrated approach represents a departure from conventional street design that typically segregates stormwater management from aesthetic and social considerations.

Rain gardens function as bioretention systems that collect, filter, and infiltrate stormwater runoff while supporting biodiversity through appropriate plant selection. In the context of street landscapes, these vegetated depressions can be incorporated into medians, curb extensions, and sidewalk planters, creating a distributed network of green infrastructure. Effective rain gardens are designed with consideration to the soil media, plant selection for varying moisture conditions, as well as all adjacent hardscape features. If designed properly, these systems can remove suspended solids and urban nitrogen and phosphorus loads by 80% and significantly.

Permeable paving represents the second key component of symbiotic street landscapes as it provides water infiltration locations through urbanised landscapes. These systems include permeable concrete, porous asphalt, interlocking pavers, and reinforced grass systems which vary in function and form. Various permeable paving technologies are chosen based on traffic volume, maintenance ability, and conditions of the subsoil. Implemented systematically, these systems can expect to achieve a 70 - 90% reduction in stormwater runoff volume during moderate rainfall events, substantially alleviating the burden on conventional drainage infrastructure.

Microclimate design deals with the modification of the climatic conditions of the street corridors to improve human comfort while maintaining ecological processes. This component deals with the urban heat island effect by the strategic use of vegetative cover, water bodies, and construction materials with low thermal mass. The cooling effects of rain gardens in combination with permeable surfaces, which are less heat retentive than traditional non-permeable materials, significantly increase cooling effects. The research, for instance, suggests that adequately planned street landscapes can lower ambient temperatures by 2-4°C during summer months.

The context of Shanghai Lingang New City poses both possibilities and difficulties in the application of symbiotic street design. It is located at the easternmost edge of Shanghai, at Pudong New Area, and this planned district functions as a testing site for emerging concepts for urban infrastructure. Being coastal, the region is monsoonal with an average annual precipitation of about 1,200mm, mostly falling during summer. This pattern of precipitation is advantageous in terms of flood management, though poses challenges in terms of water harvesting. Primarily flat areas pose a need for grading, while the underlying soil presents unique infiltration challenges that require specially tailored design solutions.

Implementation of sponge cities in Shanghai has undergone regulatory change in the context of the 2015 national initiative. The Shanghai Sponge City Construction

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Technical Guide (2016) has set specific performance thresholds which include, among others, 70% annual rainfall retention onsite and controlled runoff from design storms. The policies provide both carrots and sticks for incorporating sponge city techniques within new development areas such as Lingang. However, translating these requirements into cohesive streetscapes poses the challenge of integrated design beyond the interdisciplinary walls of civil engineering, landscape architecture, and urban design.

The theoretical framework captured in Figure 1 illustrates the need for balanced street landscapes that symbiotically integrate ecological, hydrological and social functions—not as individual parts, but rather as a single cohesive unified design approach. This thinking is in line with developing perspectives on urban infrastructure as multi-purpose networks capable of enhancing the quality of public spaces through ecosystem services. Focus now shifts to describing particular approaches to design performed on street landscapes in Lingang describing how these approaches succeed or fail in achieving such integration.

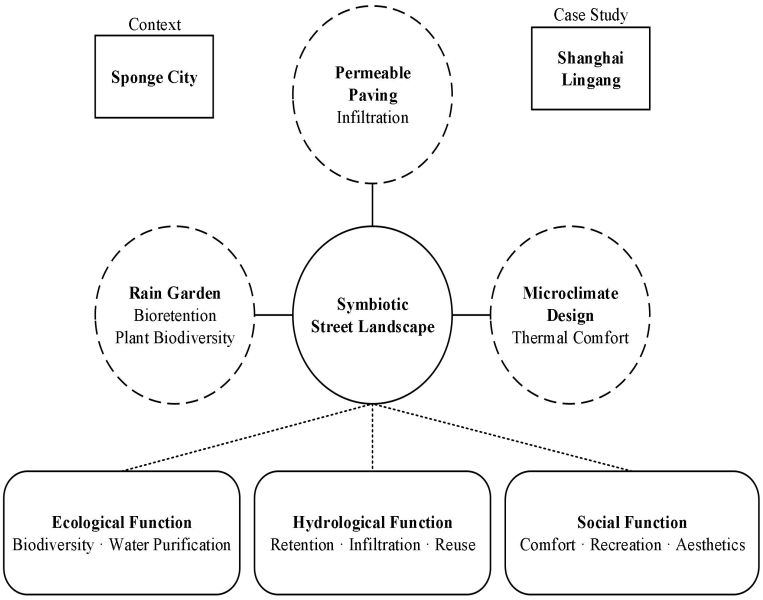

Figure 1: Theoretical Framework for Symbiotic Street Landscape Design

3 Methodology and Case Study Analysis

The case of symbiotic street landscape design in Shanghai Lingang New City integrates the principles of sponge city and public space development. In this case, particular design interventions are studied for rain gardens, permeable paving, and enhancement of microclimates which they analyse across three different street types. This approach combines the analysis of functional performance with the evaluation of social and artistic aspects of design, as it is argued that balanced symbiotic design must address competing demands simultaneously.

The street landscapes of Lingang incorporate integrated rain garden systems that are a result of careful design in plant selection and soil shaping. The bioretention areas incorporate a three-layer vertical structure: a surface vegetation layer dominated by perennial grasses and forbs that can withstand drought and periodic inundation; an

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engineered soil layer consisting of 60-70% sand, 15-25% topsoil, and 10-15% organic matter that can support and sustain plant life while facilitating filtration; and a drainage layer of graded aggregate containing perforated pipes which collects filtered water for infiltration or harvesting. Selection of species has focused on and extended to drought-adapted natives like Miscanthus sinensis, Iris pseudacorus, and Lythrum salicaria for wet zones, while the upper portions of the rain gardens feature more drought-tolerant Pennisetum alopecuroides and Calamagrostis brachytricha.
The space arrangement of rain gardens differs with street types and space availability. In quiet residential streets, longitudinal bioswale strips coincide with pedestrian paths. This design serves as a buffer zone between vehicle and pedestrian traffic while optimising infiltration area. In arterial roads where space is more limited, a network of bioretention cells is placed and these are integrated with transit stops and pedestrian crossings as multifunctional nodes. Integrated Systems Design performance monitoring shows these systems intercept the initial 25mm of rainwater runoff for typical storms and reduce peak runoff by approximately 65% relative to conventional street designs.
The installation of permeable paving in Lingang resolves the problem dealing with balancing the function of infiltration with the varying traffic durability considerations. The design strategy features a gradient of solutions: parking lanes and pedestrian zones make use of paver blocks with 8-12% voids, fully capturing and allowing water to drain while retaining structural support, within a soft landscape setting; bicycle tracks are constructed using smooth resin-bound permeable surfacing that maintains water permeability whilst providing a good ride; and low-use service roads employ pervious concrete made with specially designed aggregate blends that improve permeability and durability simultaneously. This approach captures the fact that within complex street contexts, no single permeable paving design can meet all functional demands.
Lingang's permeable paving systems are specifically tailored to local concerns such as high water tables and weak subsoil drainage in some locations. The standard section comprises a wearing course of 80-100mm, a bedding layer of 50mm clean aggregate, a transition layer of 100mm, and a reservoir layer of 150-300mm depending on the required storage capacity. In regions with low infiltration rates, these systems tie into a box network of subsurface drainage which takes clean water to community scale retention ponds. Several maintenance actions have been tailored to safeguard enduring usefulness, such as routine vacuum sweeping four times a year and annual infiltration testing to identify problem areas.
The strategies and methods used in the design focus on increasing the environmental and thermal comfort standards as well as maintaining the stormwater management systems. The planting of street trees follows climate-responsive reasoning where deciduous trees like Ginkgo biloba and Zelkova serrata provide summer shading and permit winter solar access along east-west corridors. North-south streets make use of evergreen and deciduous species that provide year-round wind modification with seasonal wind benefits. The water features incorporated into the landscape take advantage of evaporative cooling, with linear water runnels connecting rain gardens
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during wet times and becoming visually pleasing dry channels during droughts. Thermal imaging studies show that integrated landscapes reduce summer afternoon surface temperatures by 6-8°C compared to adjacent districts with conventional streets.

The systematic incorporation of individual elements has resulted from multidisciplinary design processes that resolve conflicts among systems. For instance, subsurface utilities have been streamlined into separate aligned corridors to create uninterrupted spaces for the roots of trees and bioretention areas, while smart irrigation systems rely on harvested stormwater to supply water to the plants during dry spells. These strategies are also applied to construction sequencing and maintenance routines so that all processes operate in harmony throughout the system's life cycle.

Assessing the implementation of Lingang’s symphonic street landscapes shows that the overall performance has improved across multiple metrics. Hydroscopically, the systems operate relatively well and manage on-site rainfall by 75% of the annual total; this exceeds the 70% target set under the sponge city guidelines for Shanghai. Ecologically, the ecological planting palettes support insect populations and inspire biodiversity growth by approximately 3.5 times compared to ordinary streetscapes, providing sustenance to wider ecological corridors. Sociologically, pedestrian counts suggest a 45% rise in non-commuting travelling pedestrians, indicating increased acceptability on streets of similar size and location relative to longitudinal control counterparts, which suggests improved public utilisation. The spatial experience enhances comfort and the feeling of safety. These results illustrate how blended symbiotic designs, coupled with reasonable technical performance standards, accomplish active public space engagement.

4 Discussion and Future Directions

The deployment of symbiotic street landscape design in Shanghai Lingang New City serves as an exemplar for sponge city implementation within an urban context. This case study illustrates that the combined use of rain gardens, permeable paving, and microclimate design can simultaneously achieve stormwater management, increased biodiversity, improved microclimatic conditions, and enhanced public spaces. Key success factors of the implementation in Lingang were the integrated policy frameworks, multidisciplinary design cooperation, and efficient performance evaluation enabling flexible management.

Scaling these approaches up to broader urban areas poses several challenges. Maintenance of integrated landscapes is more difficult and may require discretion from several municipal departments, as these systems are more complex than traditional street landscapes. Initial construction costs are also higher; conventional street construction costs need to be increased by 15-20%, which may be a hurdle for resource-strapped municipalities. However, the long-term reduced flood damages and increased property values could offset these costs over time. Furthermore, the system's performance dependent on the season presents communication challenges with a range of stakeholders during expectations management in extreme weather.

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Lingang's design strategies can be transferred to other urban contexts only after evaluating certain climate conditions, infrastructure, and legal policies. While the underlying concepts of symbiotic integration can be implemented in diverse settings, some exact technological approaches may require adaptation to regional circumstances. It would be prudent to explore further the development of modular approaches to urban design where fundamental principles of symbiotic integration remain intact but can be adapted to different urban typologies.

As for policies developed from this research, they would suggest the creation of integrated evaluative criteria that concurrently capture the hydrological, ecological, and social value of the landscape and multifunctional street-symbiotic ecological incentive systems prioritising symbiotic yard landscapes; as well as technical capacity building initiatives in planning, design, or landscape maintenance arms of the required interdisciplinary sustaining technological competencies. Moving towards truly symbiotic urban environments does not only require technical advancements but a complete paradigm shift of how infrastructure, ecology, and public space are integrated and perceived in contemporary cities.

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