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LANDSCAPE URBANISM SUPPORTS SPONGE CITY DEVELOPMENT IN THE HANGZHOU ASIAN GAMES VILLAGE

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Abstract: This study investigates the influence of landscape urbanism design and green infrastructure on the performance of sponge cities, an increasingly vital approach to sustainable urban water management in rapidly urbanizing contexts. Focusing on the Asian Games Village in in Hangzhou as a case study, the research explores the mediating role of stormwater management efficiency and the moderating effect of government policy support in this relationship. A quantitative method was employed, utilizing data from structured questionnaires completed by 296 urban development professionals. The hypothesized relationships were analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings confirm that both landscape urbanism design and green infrastructure significantly and positively impact sponge city performance. Stormwater management efficiency was identified as a crucial mediator in these relationships. Furthermore, the results revealed that government policy support acts as a moderator, strengthening the positive effects of landscape urbanism and green infrastructure on stormwater management. This research contributes a comprehensive conceptual model that integrates ecological design principles, operational performance, and governance frameworks. It provides practical guidance for urban planners and policymakers by highlighting the necessity of a systemic approach that combines innovative design with robust policy to create resilient and effective sponge cities, thereby advancing both theory and practice in sustainable urban development.

Keywords: landscape urbanism, sponge city, green infrastructure, stormwater management efficiency, government policy support

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INTRODUCTION

Urbanization and global climate change heightened stormwater management and prevention of urban flooding concerns within cities around the world, especially in developing Asian cities (Abhijith et al., 2025) The "sponge city" is a desirable approach to maximizing urban resilience via encouraging natural absorption, storage, and purification of rainwater in cities (Chen, 2023). Sponge city planning promotes the use of green infrastructure and ecological design principles in urban planning in an effort to minimize surface runoff, remove flood threats, and enhance water quality (Chikhi et al., 2024).

Landscape urbanism, which concerns itself with merging ecological systems with urban planning, provides an interesting model for addressing the challenges of sponge cities through the creation of multifunctional spaces for human and environmental advantage (Balon et al., 2023). Specifically, planning of mass event villages, like the Asian Games Village, presents a chance to implement landscape urbanism as an integrated method in developing resilient and sustainable cities capable of managing water and enhancing human health (Aderyani et al., 2025; Daniels & Tichaawa, 2025). Research on major Chinese cities further indicates that metropolitan development is shaped by interacting economic, political, infrastructural, social, and cultural forces (Li & Dawood, 2016a). A substantial body of evidence underscores the efficacy of landscape urbanism in enhancing urban ecological performance, particularly in stormwater management. Core principles of landscape urbanism, such as ecological zoning and multifunctional landscapes, play a vital role in reducing impervious surface cover and increasing infiltration capacity—both of which are critical for effective stormwater retention and filtration.

Green infrastructure components such as bioswales, rain gardens, and green roofs further complement this approach by significantly reducing runoff volumes and improving water quality. Empirical studies from Chinese cities, for example, report up to 60% reductions in stormwater runoff during heavy rainfall events following green infrastructure implementation.

These strategies collectively contribute to improving sponge city performance by strengthening natural hydrological cycles and mitigating urban flood risks. Furthermore, stormwater management efficiency has emerged as a key mediating factor, influencing the relationship between ecological urban design strategies and overall sponge city outcomes. High-performing stormwater systems enhance the regulation of flow rates, pollutant loads, and water recycling capabilities. Government policy support also plays a moderating role, with financial incentives and regulatory frameworks significantly shaping the adoption and success of sustainable water management practices (Abhijith et al., 2025; Carranza, 2024; Grabowski et al., 2023; Grichting & Salama, 2024; Huang et al., 2025; Khoshhalshaghaji et al., 2025; Kurniawan et al., 2023; Ling et al., 2024; Mao

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et al., 2025; Mendes et al., 2025; Štrbac et al., 2023). More broadly, resource-efficient innovation has been identified as a pathway toward sustainable development under technological and market turbulence (Iqbal et al., 2021).

Despite the widening knowledge base, several gaps exist in understanding the complex interactions among landscape urbanism design, green infrastructure implementation, and sponge city performance (Su & Tan, 2023; Tang et al., 2025; Zammit, 2025). First, much research to date focuses on these variables individually or considers green infrastructure technology without much consideration of the principles of landscape urbanism generally (Mendes et al., 2025). This fragmented approach restricts the fulfillment of comprehensively knowing how multifunctional urban typologies interact with stormwater systems and collectively contribute to urban resilience (Mao et al., 2025; Zhixin et al., 2025). Secondly, the mediating role of stormwater management efficiency in connecting ecological design strategies and sponge city outcomes remains insufficiently investigated, especially concerning massive-scale, transient urban complexes like the Asian Games Village (Wang et al., 2025). This gap highlights the need for empirical models to explicitly measure the way through which stormwater management acts as an avenue for design interventions to manifest into functional performance upgrades (Grichting & Salama, 2024; Liu, 2023). In addition, the moderating role of the support of government policy towards landscape urbanism and green infrastructure performance is still not adequately addressed in current studies (Balon et al., 2023). Although policy frameworks are well-documented to be key enablers, hardly any empirical studies have been conducted to examine how varying levels of policy strength and enforcement influence the relationship between design implementation and the effectiveness of stormwater management (Adedeji & Lenz, 2023; Kim, 2025; Mendes et al., 2025). This is particularly salient in the Asian context where governance arrangements in urban areas and policy environments vary considerably and impact the scalability and sustainability of sponge city initiatives (e Ali & Bashir, 2024). Closing these gaps is vital to constructing more robust, context-related frameworks that can advise on integrated urban water management strategies and help drive sustainable urban change in mega-event settings and other locales.

This article attempts to explore the complex relationships between landscape urbanism design, green infrastructure uptake, stormwater management efficacy, and sponge city performance, while highlighting the moderating role of government policy support in the context of the Asian Games Village in Hangzhou. The key objectives are: (1) to assess the direct relationships between landscape urbanism and green infrastructure and sponge city performance; (2) to examine the mediating role of stormwater management efficiency in these relationships; (3) to look at government policy support as a driver of the magnitude of these relationships. This study contributes to practice and theory significantly by providing a common model that integrates ecological design, infrastructural technology, and policy intervention in order to optimize sponge city performance. In its examination of the Asian Games Village a mega urban development project with high profile this study offers valuable information on the implementation of principles of landscape urbanism to problem conditions in the city in which sustainability and resilience are critical (Carranza, 2024). The results are anticipated to enlighten urban planners, policymakers, and environmental managers on the integral role of integrated design and governance interventions in ensuring appropriate management of stormwater and urban resilience, respectively. In addition, the research is bridging significant knowledge gaps, specifically in mediating and moderating factors influencing urban water management outcomes, thereby adding value to sustainable urbanism as a research field across Asia and the world (Suits et al., 2025).

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Landscape Urbanism Design and Sponge City Performance

Landscape urbanism planning is a planning and design approach that introduces ecological processes and landscape systems into the urban environment (Balon et al., 2023). Ecological zoning, one of its central principles, is based on the separation of city space by natural elements and environmental functions and multifunctional space that has several functions, including recreation, habitat provision, and stormwater management (Carranza, 2024). These design principles are responsible for the development of robust urban environments that enhance natural hydrological processes, biodiversity, and human well-being (Hoover et al., 2023; Mamirkulova et al., 2025). Sponge city performance, in this article, evaluates the capacity of the urban environment to capture, retain, and filter rainwater, thus barring the possibilities of flooding and water usage sustainability (Chikhi et al., 2024). Ecological zoning can minimize impervious surface flow through safeguarding natural water retention areas and preventing development from advancing to vulnerable areas (Ji & Rao, 2023). Multifunctional space, for example, parks with wetlands or retention basins, both control stormwater effectively and increase city and community appeal (Liu, 2023). Studies in various Asian cities confirmed that sites designed based on landscape urbanism principles have higher infiltration capacity and greater resilience during heavy rainfalls (Jensen & Cureton, 2024). Evidence supports the assumption that sponge city performance is positively affected by landscape urbanism design through the incorporation of ecological health and urban efficiency (Liang & Li, 2023; Liu et al., 2025).

H1: Landscape urbanism design significantly contributes to sponge city performance.

Green Infrastructure Application and Sponge City Performance

Green infrastructure refers to a decentralized network of natural systems that are designed to manage stormwater at the source (Grichting & Salama, 2024). Filter- and runoff-conveying bioswales, rain gardens for rainwater storage and infiltration, and green roofs for mitigating surface runoff by harvesting rainfall are the primary elements (Hapriyanto & Azmi, 2025). The elements support sponge city performance through enhanced infiltration, peak runoff attenuation, and improved water quality. Green infrastructure also contributes to cooling urban areas, maintaining biodiversity, and promoting greater environmental sustainability, and is therefore a major method for cities to combat dealing with climate change as well as metropolitan pressure (Khoshhalshaghaji et al., 2025). There is ample empirical evidence which bears witness to the fact that green infrastructure allows sponge city to function effectively (Kim, 2025). There are reported consultations of sizeable runoff reductions and consultations of pollutant loads in urban spaces where rain gardens and bioswales have been implemented, especially in spaces with high intensity rainfall events (Ling et al., 2024). Green roofs, among other structures, have been reported to decrease runoff volume by up to 70%, with other thermal insulation properties (Mendes et al., 2025). Singaporean and Chinese urban case studies offer insights into the ways in which the massive deployment of green infrastructure results in the control of floods and improved urban microclimates (Štrbac et al., 2023). They form the basis of theory that green infrastructure development is a significant driver of improved sponge city performance, thus being a real-world, scalable means of sustainable urban water management.

H2: Effective implementation of green infrastructure contributes positively and significantly to sponge city performance.

Efficiency of Stormwater Management and Sponge City Performance

The efficiency of stormwater management systems and processes to treat precipitation volume and quality during and following rainfall is referred to as stormwater management effectiveness (Yadav et al., 2025). It involves features like peak flow control, enhanced infiltration, and cleaning of pollutants prior to runoff into natural water bodies (Wang et al., 2025). Appropriate stormwater management in sponge cities is important, and the challenge is to replicate the natural hydrology to alleviate flooding, recharge groundwater, and sustain urban ecological balance (Suits et al., 2025). Key performance indicators are decreased volume of runoff, decreased concentration of pollutants, and increased groundwater recharge rates (Stinshoff et al., 2025). The more sophisticated stormwater controls of more advanced cities such as detention basins, permeable pavements, and constructed wetlands have significantly lower urban flooding and water pollution rates (Mendes et al., 2025). Asian cities in their research have established that the improvement of stormwater management measures reduces surface runoff volumes by significant quantities, thus decreasing the burden on drainage infrastructure (Mao et al., 2025). These results verify the premise that the effectiveness of stormwater management positively influences the performance of sponge cities by regulating the urban system's capacity to sustain rainfall and reduce risks.

H3: The efficiency in stormwater management has a direct positive effect on the performance of the sponge city.

Stormwater Management Efficiency as Mediator

Landscape urbanism design prioritizes logical location of ecological and multifunctional spaces to enhance urban sustainability and resilience (Mao et al., 2025). The most important variables include the aspects of the design, such as ecological zoning, green corridors, and multifunctional landscapes, which enhance natural water flow and retention. Stormwater management performance refers to the degree to which urban infrastructure handles runoff volume, flow rates, and pollutant loads by functioning (Khoshhalshaghaji et al., 2025). The performance of the sponge city serves as an indicator of how well the city performs in recycling and holding back stormwater and thereby reduces flood risk and sustains ecological balance (Ma et al., 2023). The mediating role of stormwater management efficiency reveals that the advantages of landscape urbanism design in sponge city performance are primarily driven by improved capacity to handle stormwater (Liu, 2023). For instance, multifunctional landscapes in ecological zoning reduce impervious cover and increase infiltration and runoff regulation accordingly (Liu et al., 2025). Studies on Asian cities support that stormwater infrastructure incorporated in landscape urbanism planning optimizes peak flow reduction and water quality improvement benefits, and achieves effective stormwater management (Baghersad et al., 2025).

H4: The relationship between landscape urbanism design and sponge city performance is mediated by stormwater management efficiency.

Green infrastructure installation consists of integrating stormwater locally treated nature-based solutions, including bioswales, rain gardens, and green roof systems, within the urban setting. They enhance infiltration, reduce runoff, and enhance pollutant removal (Huang et al., 2025). The effectiveness of stormwater management, here used as a mediating variable, describes the extent to which such green infrastructure components maximize control of water quality and runoff in an efficient manner and thus affect citywide sponge city performance, where the urban system's capability to absorb, store, and reuse stormwater in a sustainable way is quantified (Kong et al., 2025). Thousands of studies have established that green infrastructure improves stormwater management efficiency through detrainment and filtration of contaminants and reduction and filtration of runoff peaks, respectively (Zhu et al., 2023). For instance, in an urban landscape, bioswales and rain gardens reduce volume runoff and retard peak discharge, thus improving the hydrologic capacity of urban catchments to absorb stormwater (Zhixin et al., 2025). In addition, green roofs have runoff reduction and thermal management benefits too, which supports improved hydrological performance additionally. These results show that the beneficial role of green infrastructure on sponge city performance primarily exists through its optimizing effectiveness of stormwater management (De Montis et al., 2024). Thus, stormwater management takes the functional bridge role to facilitate applications of green infrastructure to achieve its resultant benefit in sustainable urban water management.

H5: Stormwater management efficiency mediates the relationship between green infrastructure implementation and sponge city performance.

Government Policy Support as Moderator

Government policy support involves the policies, regulations, incentives, and financing instruments that make and promote sustainability-oriented approaches towards urban development (Alanazi et al., 2025; Ziari & Mosleh, 2025). Some of the most critical variables include policy interventions like zoning codes, environmental policies, fiscal policy incentives, and planning requirements that promote the use of landscape urbanism design principles (e Ali & Bashir, 2024). Whether or not stormwater management is successful serves as a proxy measure of the performance or effectiveness of how urban systems succeed in regulating and maximizing stormwater flow and quality (Kurniawan et al., 2023). Government policy support as the moderating variable means that the positive impact of landscape urbanism design in enhancing stormwater management efficiency is more pronounced when it is supported vigorously by policies (Su & Tan, 2023). Empirical evidence indicates the requirement for policy environments to allow landscape urbanism to play its maximum possible role in urban water management (Baghersad et al., 2025). For example, cities with integrated green urban policy measures are bound to experience higher degrees of stormwater management and less flooding since they benefit from enhanced ecological zoning as well as multifunctional landscapes (Huang et al., 2025). Studies conducted in China and Singapore highlight how supportive policy settings facilitate cross-sector collaboration, allocate resources to landscape projects, and implement standards that enhance stormwater performance (Khodadad et al., 2023; Mendes et al., 2025; Zarei & Shahab, 2025). These findings validate the hypothesis that government policy support strengthens the relationship between landscape urbanism design and the effectiveness of stormwater management by providing the institution and funding necessary to overcome practical barriers and scale up successful interventions.

H6: Government policy support moderates the relationship between landscape urbanism design and stormwater management efficiency.

The deployment of green infrastructure involves mixing bioswales, permeable pavements, rain gardens, and green roofs in urban areas with a goal of managing stormwater in an environmentally friendly manner (Mao et al., 2025). Support in government policy through mixes of enabling tools such as environmental standards, finance schemes, technical specifications, and societal campaigns promoting the uptake of green infrastructure (Stinshoff et al., 2025). The efficiency of stormwater management measures the strength of cities to manage runoff volume, peak discharge, and pollutant load. The policy support moderation role indicates that this enhancing role of green infrastructure in stormwater management efficiency is intensified once the government provides substantial support and promotes it (Kong et al., 2025). Research has indicated that well-planned government policies are at the forefront in the proper implementation and functioning of green infrastructure in urban water management (Huang et al., 2025). For example, a policy incentive is stormwater fee credits and tax rebates, which have been shown to accompany higher rates of installation and maintenance of green infrastructure. In addition, planning regulations and regulatory requirements ensure that green infrastructure is incorporated in urban development plans in time to optimize its hydrological effectiveness (Zarei & Shahab, 2025). Portland and Seoul are examples or case studies demonstrating how policy support is correlated with enhanced stormwater performance, such as minimized flooding and better water quality.

H7: Government policy support moderates the relationship between green infrastructure implementation and stormwater management efficiency.

Theoretical Framework Supporting the Research

This research is grounded on the socio-ecological systems theory and urban thinking about resilience, which involves the dynamic interaction between human-built infrastructure and nature with a view to the development of resilient urban areas. Landscape urbanism design and green infrastructure are practiced as the focal ecological treatments that mimic the natural hydrological processes and thus enhance the efficiency of stormwater management a core process through which the performance of sponge cities is optimized (Jensen & Cureton, 2024). Theory suggests that urban systems work best when policy, design, and ecological elements are integrated into harmony with each other, emphasizing the government policy support function as a moderating variable in enhancing implementation and performance of green infrastructure and landscape urbanism interventions (Owojori & Erasmus, 2025). Moreover, stormwater management effectiveness serves as a mediating variable to convert design and investment in infrastructure into quantifiable impacts on sponge city performance because theories of environmental governance propose the interconnection between environmental and technological efficacy and institutional support. Such integrated planning offers a strong framework for understanding the intricate interdependencies of urban water governance and stresses the importance of integrating ecological planning, technological implementation, and policy instruments for the purpose of achieving sponge cities that are adaptive and resilient. The conceptual model of these postulated relationships is found in Figure 1, the direct effects of landscape urbanism planning and green infrastructure implementation on the performance of sponge cities, mediated by stormwater management effectiveness, and moderated by government policy support.

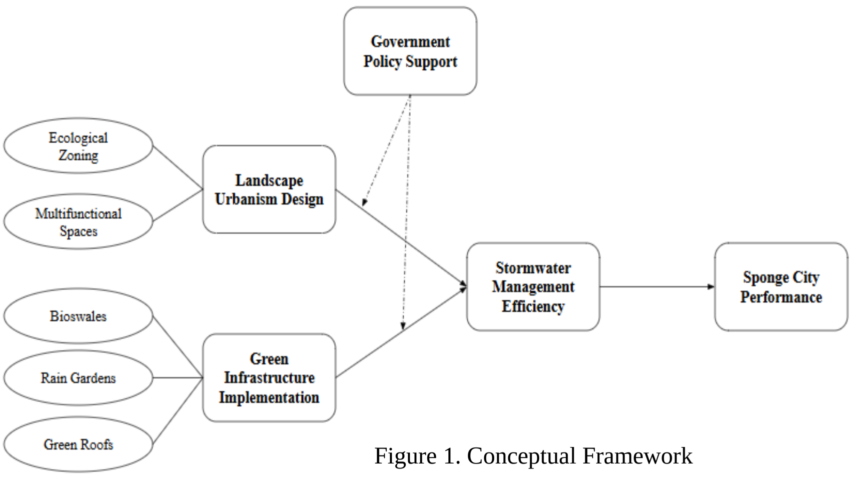

Figure 1. Conceptual Framework

METHODOLOGY

Research Design

In this research, a quantitative study design was used in an attempt to test hypothesized relationships between the main variables of sponge city performance in the context of the Asian Games Village 19th Hangzhou. More precisely, a cross-sectional survey design was used in collecting data from key stakeholders at one point in time. The application of quantitative methodology facilitated the empirical measurement of constructs such as landscape urbanism design, green infrastructure adoption, stormwater management effectiveness, and government policy enablement. Such a design facilitated the implementation of sophisticated statistical analyses to investigate direct, mediating, and moderating effects in the conceptual model proposed, hence conducting comprehensive empirical testing to corroborate or falsify the research hypotheses.

Population

The target population for this research consisted of individuals who were directly engaged in planning, designing, implementing, and governing the urban development projects of the Asian Games Village. They formed the group consisting of urban planners, landscape architects, civil and environmental engineers, sustainability advisors, and municipal policy makers possessing expert knowledge or experience in the context of sponge city initiatives, ecological urban design, and stormwater management practices. Such people have the necessary knowledge to give educated answers regarding the technical, design, and policy implications of sponge city development.

Sample Size and Sampling Technique

A purposive sampling method was utilized to choose respondents who were either directly engaged in the design, planning, or implementation of sponge city infrastructure within the Asian Games Village or possessed significant professional experience in related disciplines like landscape urbanism, environmental planning, or urban water management. The inclusion criterion demanded that participants: (1) work full-time in the fields of urban planning, landscape architecture, civil or environmental engineering, sustainability consulting, or local government, and (2) possess professional experience working on green infrastructure or stormwater management projects, preferably large-scale urban development. A list of organizations concerned, such as municipal departments, environmental departments, and private planning companies engaged in the Asian Games Village or comparable ventures, was made to select eligible respondents. 350 professionals were approached from this list, and 296 usable responses were obtained, giving an effective response percentage of 84.6%. The sample size is above the suggested limit for PLS-SEM, and it provides sufficient statistical power for analyzing complex

Data Collection

The data collection for the study was through a standardized, self-completed questionnaire that was meant to measure perceptions and experiences on landscape urbanism design, implementation of green infrastructure, effectiveness in stormwater management, government policy support, and performance of sponge cities. All the measurement items were taken from established instruments used in previous studies to ensure construct validity and reliability. Prior to the main data collection, a pilot test was applied to a sample of 15 urban planners, civil engineers, and sustainability consultants. Feedback from them was used to eliminate ambiguity in the questionnaire's language for contextualization and professional suitability, so that questions were both professionally suitable and comprehensible. Online and offline methods were adopted for data collection. The online questionnaire was circulated through email and professional platforms like LinkedIn to reach those associated with urban development and ecological infrastructure projects in China. Meanwhile, questionnaires based on paper were sent out during professional seminars, workshops of stakeholders, and project meetings concerning the development of sponge city in Hangzhou and surrounding areas. The three-month period for collecting data was used to cater to the diversified availability of professionals and provide adequate response time. The survey instrument included items measuring landscape urbanism design, green infrastructure implementation, stormwater management efficiency, government policy support, and sponge city performance, all rated on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree).

Data Analysis

Data analysis was conducted using SmartPLS 4.0, a software tool designed for Partial Least Squares Structural Equation Modeling (PLS-SEM). The analysis followed a two-step approach: assessment of the measurement model and evaluation of the structural model. The measurement model was first tested to confirm reliability (using Cronbach's alpha and composite reliability) and validity (through convergent validity via Average Variance Extracted and discriminant validity using the Fornell-Larcker criterion). Once the measurement model was validated, the structural model was analyzed to test the hypothesized relationships, including direct, mediating, and moderating effects. Bootstrapping with 5,000 subsamples was employed to evaluate the significance of path coefficients. Additionally, the model's explanatory power was assessed using R^2 values, and model fit was verified through the SRMR index. This rigorous analytical process ensured robust empirical testing of the conceptual framework and hypotheses. PLS-SEM has also been applied in Chinese urban research to evaluate multiple drivers of city development (Li & Dawood, 2016b).

RESULTS

Table 1 and Figure 2 shows the reliability and validity measures of the major latent constructs in the study. All the constructs are highly reliable, as evidenced by Cronbach's alpha levels above the cut-off of 0.70. The values are between 0.774 for sponge city performance to 0.893 for landscape urbanism design, implying acceptable to exemplary reliability.

Table 1. Variables reliability and validity

	Cronbach's alpha	CR	AVE
Green Infrastructure Implementation	0.882	0.913	0.677
Government Policy Support	0.878	0.911	0.674
Landscape Urbanism Design	0.893	0.922	0.702
Sponge City Performance	0.774	0.846	0.527
Stormwater Management Efficiency	0.861	0.900	0.643

Composite reliability (CR) scores also attest to this internal consistency with all the constructs having a score greater than the acceptable value of 0.70, ranging from 0.846 to 0.922.

In the area of convergent validity, the average variance extracted (AVE) for all the constructs exceeds the recommended value of 0.50, thereby asserting that a high percentage of variance is explained by the indicators. Most importantly, landscape urbanism design bears the largest AVE at 0.702, showing robust construct representation by its measurement items. The findings uphold the reliability and convergent validity of the measurement model.

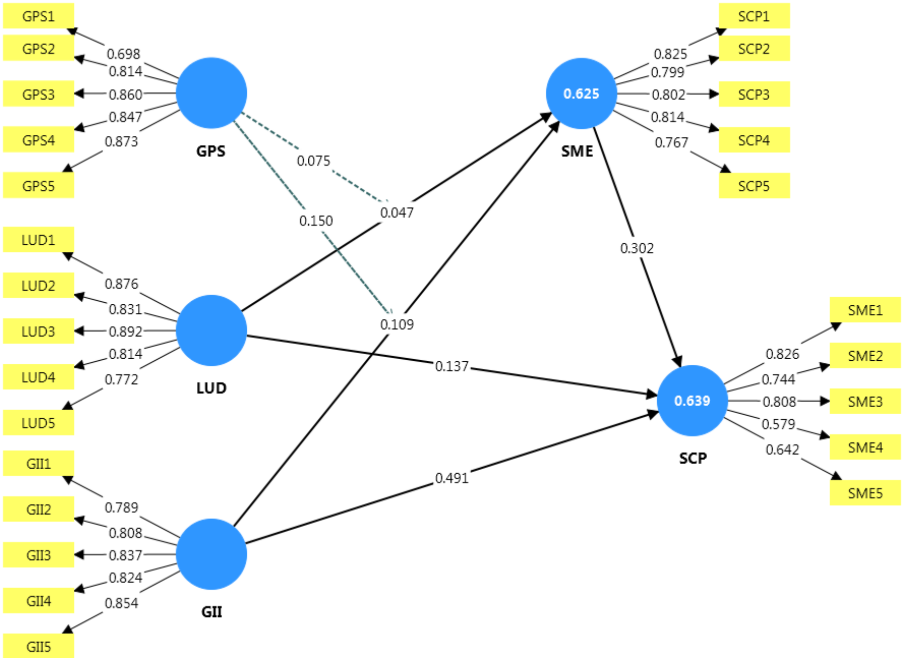

Figure 2. Estimated Model

Table 2 presents the outer loadings and variance inflation factor (VIF) values of all the measurement items for the five constructs. Outer loadings largely surpass the threshold of 0.70, depicting high item reliability and establishing that individual indicators noticeably contribute to their respective latent variables. One exception is SME4 for stormwater management efficiency, with a loading of 0.579, just below the desired cutoff but also in acceptable range for exploratory research. VIF values for all items are less than the critical value of 5, showing no serious multicollinearity problem among indicators. The set of VIF values (1.495 to 3.274) also attests to the fact that there is no possibility of collinearity to jeopardize the estimation process, and hence the measurement model is robust.

Table 2. Outer Loading and VIF

Variables	Items	Outer Loading	VIF	Variables	Items	Outer Loading	VIF
Green Infrastructure Implementation	GII1	0.789	2.724	Sponge City Performance	SCP1	0.825	2.064
	GII2	0.808	3.065		SCP2	0.799	1.811
	GII3	0.837	2.514		SCP3	0.802	1.916
	GII4	0.824	2.786		SCP4	0.814	1.980
	GII5	0.854	3.274		SCP5	0.767	1.793
Government Policy Support	GPS1	0.698	1.634	Stormwater Management Efficiency	SME1	0.826	2.247
	GPS2	0.814	2.158		SME2	0.744	1.772
	GPS3	0.860	2.609		SME3	0.808	1.888
	GPS4	0.847	2.543		SME4	0.579	1.495
	GPS5	0.873	2.800		SME5	0.642	1.696
Landscape Urbanism Design	LUD1	0.876	2.775				
	LUD2	0.831	2.167				
	LUD3	0.892	3.122				
	LUD4	0.814	2.124				
	LUD5	0.772	1.748				

Table 3. Discriminant Validity

	GII	GPS	LUD	SCP	SME
Green Infrastructure Implementation					
Government Policy Support	0.528				
Landscape Urbanism Design	0.631	0.697			
Sponge City Performance	0.838	0.787	0.815		
Stormwater Management Efficiency	0.532	0.704	0.634	0.762	

Table 4. R-square statistics Model Goodness of Fit Statistics

	R-square	R-square adjusted	Q2	SRMR
Sponge City Performance	0.639	0.636	0.631	0.074
Stormwater Management Efficiency	0.625	0.621	0.62	

Table 3 reports the Heterotrait-Monotrait (HTMT) ratios to test discriminant validity between the constructs. All HTMTs are far below the conservative value of 0.85 and indicate that every construct is empirically different from the others. For instance, the HTMT ratio for green infrastructure implementation versus stormwater management efficiency is 0.532, whereas the highest ratio attained is 0.838 between green infrastructure implementation and sponge city performance—still within an acceptable level. These results affirm that the constructs have strong discriminant validity, and they support the strength of the measurement model.

Table 4 presents the model's explanatory power and overall fit statistics. The R-square for sponge city performance is 0.639, reflecting that about 63.9% of the variance in this outcome is explained by the model variables. In a similar vein, R-square for stormwater management effectiveness is 0.625, indicating high predictive power. Adjusted R-square figures are slightly lower but above 0.60, again proving the model to be strong. The Q^2 figures for both endogenous constructs are more than 0.60, showing high predictive relevance. The SRMR value of 0.074 is less than 0.08, ensuring that the model meets an acceptable level of global fit. Collectively, these figures support the validity of the model to explain and predict the results of interest.

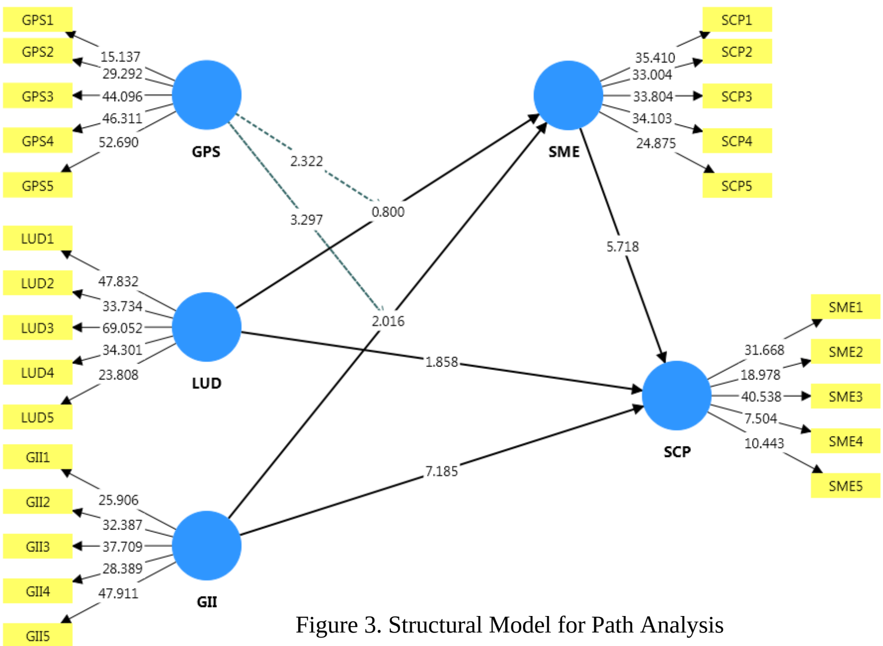

Figure 3. Structural Model for Path Analysis

Table 5 shows the outcome of the structural path analysis testing the direct, mediating, and moderating effects between the study constructs. The statistical significant path from landscape urbanism design (LUD) to sponge city performance (SCP) has a beta coefficient of 0.137, a t-value of 1.858, and a p-value of 0.032. This reflects a small but significant direct impact of landscape urbanism practice on the overall performance of sponge cities. Green infrastructure implementation (GII) reflects a high and highly significant direct impact on sponge city performance, with a beta of 0.491, t-value of 7.185, and p-value less than 0.001, indicating that green infrastructure has an important role in promoting ecological and hydrological performances in urban systems. Stormwater management effectiveness (SME) also illustrates a strong direct correlation with sponge city performance ($\beta = 0.302$, $t = 5.718$, $p < 0.001$), further establishing it as a critical working mechanism for connecting design and infrastructure with urban resilience. The mediating role of SME between LUD and SCP is statistically significant ($\beta = 0.023$, $t = 1.967$, $p = 0.025$), which indicates that stormwater efficiency partially conveys the impact of landscape design onto urban outcomes. Likewise, SME noticeably mediates green infrastructure to sponge city performance as evidenced by the beta of 0.207, t-value of 4.922, and p-value < 0.001. These findings confirm the dual mediating effect of stormwater efficiency in the hypothesized model. Additionally, government policy support (GPS) also has a significant moderating effect on the relationship between landscape urbanism and stormwater efficiency ($\beta = 0.075$, $t = 2.322$, $p = 0.010$), meaning that when policy support is high, the positive effect of landscape urbanism on stormwater results is also heightened. The relationship between green infrastructure and GPS is also stronger ($\beta = 0.150$, $t = 3.297$, $p < 0.001$), indicating that support for policy increases the efficiency of green infrastructure implementation to enhance stormwater efficiency greatly. Generally, path analysis verifies the conceptual framework, offering empirical evidence supporting hypothesized direct, mediating, and moderating relations in the sponge city development model.

Table 5. Path Analysis

	Beta	T value	P value
LUD -> SCP	0.137	1.858	0.032
GII -> SCP	0.491	7.185	< 0.001
SME -> SCP	0.302	5.718	< 0.001
LUD -> SME -> SCP	0.023	1.967	0.025
GII -> SME -> SCP	0.207	4.922	< 0.001
GPS x LUD -> SME	0.075	2.322	0.010
GPS x GII -> SME	0.150	3.297	< 0.001

DISCUSSION

With the challenges of mounting urbanization and climatic volatility, the ability of cities to adapt, absorb, and regenerate characteristics embodied by the sponge city philosophy has never been more essential. The research was conducted within the vibrant setting of the Asian Games Village, which is a flagship development that features the latest urban resilience strategies. By means of an extensive examination of design paradigms, environmental infrastructure, operation mechanisms, and institutional settings, this study aimed at unearthing the ways through which integrated city planning principles are realized as quantifiable environmental performance. The subsequent discussion interlaces the empirical findings extracted from the tested hypotheses, providing an extended interpretation of landscape urbanism's multi-level relationships with green infrastructure, stormwater management, and policy support. All accepted hypotheses not only legitimize current theoretical assumptions but also shed light on new avenues for designing and managing resilient, hydrologically smart city spaces. The results of this research offer good empirical evidence in support of hypothesis 1, which verifies that landscape urbanism design does have a strong positive effect on the performance of sponge cities. This outcome is consistent with earlier research indicating that combining landscape architecture with ecological processes does augment hydrological functionality within cities (Mohebbi & Tahbaz, 2023).

In the Asian Games Village, the integration of landscape urbanism concepts enabled improved flood management, increased infiltration, and ecological connectedness. The composition of vegetated areas and permeable surfaces would have aided natural runoff infiltration and hence alleviated the load on traditional stormwater infrastructure. These findings confirm the potential of landscape urbanism as a design philosophy for generating robust city water cycles in demonstrating the validity of the argument that multifunctional landscape design can be both effective in fulfilling aesthetic and hydrological purposes in high-density urban settings (Grichting & Salama, 2024).

Further, this research adds to the theoretical basis of the socio-ecological systems framework by revealing that highly integrated urban landscape design interventions can be vital drivers of environmental performance and resilience, particularly within large-scale, high-profile developments like event villages.

The analysis also verifies hypothesis 2, and it is revealed that the implementation of green infrastructure has a strong positive impact on the performance of sponge cities. This is consistent with available literature highlighting green infrastructure as an effective nature-based solution for urban water problems (Hapriyanto & Azmi, 2025). In the Asian Games Village, the intentional use of green infrastructure increased stormwater uptake, lessened surface runoff, and filtered pollutants, thus strengthening the city's adaptive capacity to severe rain events. Such effects imply that engineered green systems interact synergistically with natural processes to alleviate urban flooding, manage microclimates, and enhance urban biodiversity all of which are aligned with the overall objective of sponge cities. The findings extend previous research by demonstrating that the technical effectiveness of green infrastructure is also spatial and systemic, especially when implemented coherently in a vast development area. In addition, the apparent gains in performance underscore the value of embracing decentralized water management strategies, wherein various green infrastructure components scattered across a city work in concert as a networked system (Zhang et al., 2025). From both policy and planning considerations, this makes the case for requiring green infrastructure in urban design codes and incorporating it into city-wide stormwater plans.

The evidence for hypothesis 3, which posits that stormwater management efficiency plays a significant role in determining sponge city performance, highlights the importance of effective water regulation systems to the realization of the benefits of interventions based on both design and infrastructure. This interaction proves that without efficient management strategies like flow regulation, sediment control, and retention measures, the hydrological and ecological benefits of landscape urbanism and green infrastructure can never be realized (Baghersad et al., 2025). Within the framework of the Asian Games Village, efficient stormwater management resulted from synergy between structural means (e.g., underground detention tanks, smart drainage systems) and ecological measures (e.g., vegetated swales, retention ponds), together providing the site with the capability to adapt dynamically to changeable weather conditions. The strong effect of stormwater management efficiency confirms its position as an operational center of sponge city function. It also improves our knowledge of the ways in which green technologies and spatial design help to build the resilience of cities. Theoretically, the results support the mediating role of hydrological efficiency in the socio-technical landscape of urban sustainability and indicate that it is not just the existence of green features or good design that is crucial, but also how well these elements are managed and connected to the city's larger water system (Stinshoff et al., 2025). This understanding is especially applicable for engineers and urban planners, who need to see that stormwater infrastructure is not only environmentally integrated but technically optimized to accommodate climate variability as well as urban expansion stresses.

The findings are strongly in favor of hypothesis 4, which argued that stormwater management effectiveness mediates the impact of landscape urbanism design on sponge city performance. This conclusion outlines the essential process by which the spatial and ecological codes of landscape urbanism convert into measurable hydrologic benefits. While landscape urbanism injects permeable surfaces, ecological corridors, and multifunctional open spaces, it is the stormwater management systems in the end that control, direct, and put to use this spatial arrangement for water retention and absorption (Wang et al., 2025). The empirical evidence supporting this mediating relationship proves that design interventions are not enough unless supplemented by technically appropriate, operationally effective stormwater mechanisms. These findings are in line with systems-thought orientations towards sustainable urban planning, where it is held that performance results depend on the interaction between form (urban design) and function (infrastructure efficiency) (Balon et al., 2023). Landscape urbanism for the Asian Games Village was not cosmetic but functional in allowing efficient water capture, filtration, and slow release through skillfully aligned stormwater systems. Theoretically, this further justifies the case for integrated planning, under which spatial planning and hydrological engineering have to be balanced to produce the best sponge city results. It also emphasizes the importance of having urban design based on performance criteria, especially for flood-prone and high-density areas. Evidence in favor of hypothesis 5, which explored whether stormwater management effectiveness mediates the linkage between implementing green infrastructure and sponge city performance, also continues to expand knowledge on how ecological technologies perform within urban water cycles.

Although green infrastructure like bioswales, rain gardens, and green roofs are implemented to catch and treat stormwater at its origin, they perform better when part of a comprehensive, well-designed stormwater system. The mediating effect observed in the present study illustrates that the performance of green infrastructure is not merely dependent upon its existence but upon the manner in which it is managed, sized, and integrated into the general urban water infrastructure grid. This observation is aligned with previous studies that have established fragmented or degraded green infrastructure does not achieve intended stormwater control objectives (Huang et al., 2025). Within the Asian Games Village context, the green infrastructure elements were an integrated part of a greater, intelligently governed system that coordinated overflow management, sediment control, and water flow. Hence, the mediation effect validates the requirement for a hybridized model one that integrated soft ecological interventions with hard infrastructural controls (Yadav et al., 2025). Theoretically speaking, this discovery does support resilience-oriented models of urban water management, which promote adaptive systems that can function under changing conditions with ecological balance and service supply maintained.

The validation of hypothesis 6, where government policy support moderates the impact of landscape urbanism design on stormwater efficiency, supports the role of institutional and regulatory systems in ensuring efficient urban water management. The findings show that in settings where policy support is strengthened through financial rewards, planning requirements, and technical information the beneficial impacts of landscape urbanism on stormwater efficiency are greatly increased. This result resonates with the contention of (Adedeji & Lenz, 2023), who noted that the success of ecologically-oriented urban designs is highly contingent upon political will and regulative consistency. For the Asian Games Village, robust policy support allowed coordinated planning among urban designers, engineers, and environmental agencies such that landscape design was deliberately aligned with stormwater performance goals. The policy support moderating effect implies that even the most advanced landscape plans can fail without institutional support to guarantee implementation fidelity and cross-cutting integration (Tang et al., 2025). This also indicates that governance plays a part in turning sustainability principles into working realities. Theoretically, this finding highlights the usefulness of socio-institutional approaches to understanding urban resilience where governance is both driver and facilitator of ecological performance in complex urban systems.

Lastly, the hypothesis 7 confirmation to see if government policy support moderates the association between green infrastructure implementation and stormwater management effectiveness strengthens the argument further for policy as a strategic tool in the pursuit of sponge city objectives. The analysis indicates that when active support from local government, for example, subsidies for green roof construction, enforcement of permeable surface codes, or technical education for stormwater technicians is given, the effect of green infrastructure on stormwater effectiveness is more notable (Wang et al., 2023). This is in line with studies that emphasize policy as key in determining urban ecological change and overcoming institutional resistance. In the Asian Games Village, not only were there policies that required some of these green infrastructure components, but their correct maintenance and integration were also made possible through multi-agency coordination (Liang & Li, 2023). The moderating effect confirms that technical solutions alone cannot achieve dramatic changes unless the correct enabling environment is in place. It also supports the importance of cities following a governance-based perspective when incorporating green technologies. From a theoretical standpoint, the finding adds to adaptive governance discussion with a focus on responsive, collaborative, and strategically aligned policy systems as a necessary condition to scale up green infrastructure and realize long-term hydrological resilience in sponge cities.

In conclusion, the results for all seven hypotheses yield strong support for a multi-dimensional model in which spatial design, ecological infrastructure, operational efficiency, and policy alignment interact to define the success of sponge cities. Landscape urbanism and green infrastructure were found to directly and indirectly contribute to sponge city performance, through stormwater management efficiency as the mediating factor, and government policy support as the moderating factor. These cumulative interactions underscore that urban resilience is not the product of discrete interventions but of systemic thinking, integrative planning, and joined-up governance. The research reaffirms that cities need to transcend the reliance on piecemeal solutions and adopt a holistic approach one that acknowledges the interdependencies between form, function, and institution. By doing this, the likes of the Asian Games Village can be living laboratories that exhibit how forward-looking urban design can balance with environmental demands and institutional requirements to create cities that are not just livable but adaptable and future-fit.

CONCLUSION

This research probed the complex dynamics of landscape urbanism and green infrastructure toward sponge city performance using the Asian Games Village as a case study. By empirically verifying seven hypotheses, the study confirmed that landscape urbanism design and green infrastructure implementation decisively improve sponge city performance, especially when facilitated by stormwater management efficiency and underpinned by effective government policy measures. The results highlight the importance of taking a systems-thinking approach one that is aware of the interdependency between spatial planning, ecological infrastructure, operational functionality, and institutional support. In affirming the mediating and moderating mechanisms involved, the research not only enriches the theoretical discussion on urban resilience and sustainable hydrological design but also provides actionable advice for practitioners and policymakers seeking to future-proof their cities against climate-driven water risks. The Asian Games Village is an example of best practice in that it shows how visionary urban planning, supported by policy and effective infrastructure, can also bring environmental and social returns. In the process, this study adds a solid conceptual and empirical basis for pushing the sponge city agenda forward, emphasizing integration, coordination, and innovation in building adaptive, resilient, and ecologically harmonious cities.

Implications

The results of this research provide crucial practical information for urban planners, city governments, architects, and environmental engineers engaged in sustainable city planning, especially in flood-affected and high-density areas. Most importantly, the proven effectiveness of landscape urbanism and green infrastructure in augmenting sponge city capability signifies the importance of their incorporation into urban master planning models right from the beginning, as opposed to afterthoughts or stand-alone green elements. As an example, rapidly developing or redeveloping cities can implement multifunctional green areas, ecological corridors, and rain gardens both to enhance the beauty of urban streets but to realize stormwater management and flood resilience. Additionally, the major mediating effect of stormwater management efficiency highlights the necessity of investing in technical capacity, smart drainage, and maintenance procedures in order for ecological design to reflect on actual hydrological performance. Local governments must also appreciate the significance of strong policy support, which was discovered to promote the effectiveness of landscape design and green infrastructure deployment. Through the provision of regulatory requirements, economic incentives, and interdepartmental cooperation, policymakers can establish an empowering environment in which sponge city measures can flourish. The Asian Games Village, being a flagship case, offers a replicable template to other city developments in striking a balance between aesthetics, livability, and climate resilience through nature-based solutions and integrated infrastructure planning.

Theoretically, the research adds to the expanding field of sustainable urbanism, urban hydrology, and environmental governance through the provision of an integrated conceptual model that relates spatial design, ecological infrastructure, functional performance, and institutional moderation. Results confirm and generalize socio-ecological systems and urban resilience theories by empirically illustrating how physical interventions (such as landscape urbanism and green infrastructure) are mediated by operational dynamics (efficiency of stormwater management) and moderated by governance variables (policy support) to yield sustainable results. Through their revelation of these nested relationships, the research contributes to theoretical knowledge on how design and infrastructure are channeled to environmental performance in complex urban systems. The established mediation and moderation effects enrich urban sustainability literature by implying that neither design nor technology operates autonomously both must be politically enabled and systemically regulated for them to be effective. Moreover, the study emphasizes the benefit of employing hybrid models that connect technical and social theories, situating cities as dynamic systems influenced by both built environment decisions and institutional pressures. These theoretical developments can guide future studies examining resilience frameworks, adaptive infrastructure planning, and governance structures in the context of climate-responsive urban development.

Limitations and Future Directions

Although this research provides useful insights into the interactions between landscape urbanism, green infrastructure, efficiency of stormwater management, and sponge city performance, some limitations must be noted. To begin with, the study is contextual, targeting the Asian Games Village as an isolated case study, which might restrict generalizability of findings to other cities with varying climatic, geographical, or regulatory conditions. The results might differ in lower resourced cities or cities without well-established policy frameworks. Second, the research was based mainly on cross-sectional data, limiting the capacity to measure long-term impacts and temporal variations in stormwater performance or infrastructure resilience. Longitudinal research could give more in-depth insights into the development and sustainability of sponge city systems over time. Third, although the model had included policy support as a moderating factor, it had not broken down the various policy dimensions (e.g., financial incentives vs. enforcement mechanisms) that might have different effects on implementation outcomes. Comparative analyses across multiple cities, incorporation of longitudinal or real-time monitoring data, and examination of further contextual factors like community engagement, maintenance practices, or public-private partnerships could be investigated in future research. Additionally, the incorporation of qualitative methods, i.e., stakeholder interviews or policy analysis, would provide an enriched understanding of institutional dynamics and implementation constraints. Such future directions would streamline and expand the theoretical model developed in this research as well as yield more in-depth strategies for sustainable urban water management.

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Abbreviations: AVE, Average Variance Extracted; CR, Composite Reliability; GII, Green Infrastructure Implementation; GPS, Government Policy Support; HTMT, Heterotrait-Monotrait Ratio; LUD, Landscape Urbanism Design; PLS-SEM, Partial Least Squares Structural Equation Modeling; SCP, Sponge City Performance; SME, Stormwater Management Efficiency; SRMR, Standardized Root Mean Square Residual; VIF, Variance Inflation Factor.

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