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Research on Renewal Design of College Campus Based on Flood Bearing Resilience

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Abstract: In view of the flooding problems faced by colleges and universities, we first reviewed current research on flood bearing resilience in order to clarify the ideas put forth by previous studies regarding the improvement of flood bearing resilience. Then, using the China University of Geosciences, Wuhan, as an example, a framework for promoting the cooperation of various ecosystems on the college campuses to cope with flooding was established. This framework makes it possible to effectively enhance the flood bearing resilience of the college campus and promote ecological, sustainable development therein. It includes a design strategy for renewal and renovation of college campuses that can improve their resilience to flooding. In partnership with natural systems, semi-artificial and artificial ecosystems on the college campus will be redesigned to cope with rainfall and flooding. In order to increase flood bearing resilience, the proposed strategy involves systematically renovating the site, using the China University of Geosciences, Wuhan (hereinafter referred to as the CUG, Wuhan) and its surrounding area as the experimental object. This strategy of renewal has already been proven effective in and around the koi pond at CUG, Wuhan.

Keywords: flood bearing resilience; campus renewal design; semi-artificial ecosystem; artificial ecosystem

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1. Introduction

Human activities have caused a significant impact on the natural environment, resulting in global climate change. As a result of global warming, the velocity of Earth's hydrological cycle has increased, causing an increase in heavy rainfall [1]. In addition, with continuous urban expansion and development, population density and infrastructure density continue to increase, exacerbating the urban heat island effect and enhancing the air convection phenomena in urban areas [2]. As a result, the probability of heavy rainfall has increased. Furthermore, the expansion of cities encroaches upon wetlands and forests which leads to an increase in impermeable areas. During rainy weather conditions, when there is a high risk of flooding, there may not be enough space for water storage, which can lead to reduced infiltration rates below ground level and a rapid increase in surface runoff [3]. Because of the large land area, multiple climate zones, complex and diverse terrain, high population, and concentrated socio-economic production activities in China, extreme weather problems can cause more diverse and severe effects. In recent years, many Chinese cities have been damaged by heavy rainfall. Furthermore, due to the lagging urban drainage system and lack of updates and repairs, the speed of urban drainage is limited [4]. In addition, there are some flaws in the urban flood control management system. Due to the combined actions of several different disaster-causing factors, the problem of urban flooding has become more serious [3]. The safety, way of life, and social and economic development of the population have been damaged to varying degrees. Some of the older college campuses, on which teachers, students, and residents live, have high infrastructure load pressure. The flood prevention facilities on these campuses are old, and the funds for facility renovation are limited. Their ability to cope with rain and flood problems is weakening yearly. It is therefore necessary to broaden the spectrum of problem-solving ideas and to seek to utilize the synergistic action of multiple environmental factors and form a three-dimensional framework for coping with potentially disastrous college campus flooding. The objectives of this study are to develop effective ideas and methods for improving local response to stormwater problems, to improve regional flood resistance capacity, to reduce response time in the mitigation of stormwater problems, and to accelerate regional adaptation to stormwater damage in order to reduce the risk of disaster.

The following content expounds on the meaning of different types of resilience, differentiates the concepts of engineering resilience and ecological resilience, and elaborates on urban resilience and flood resilience. It gives a clear understanding of resilience in terms of urban planning and community flood resilience in the form of a table, which enables this study to focus on community flood resilience on college campuses.

1.1. Concept of Resilience

Resilience is derived from the Latin word resilio, which was originally used in physics and mathematics. With the development of industry, the concept of resilience has been increasingly applied in many professions. Resilience can refer to the resilience of a material or device to a sudden or gradual impact [5]. Ecologist C. S. Holling (Crawford Stanley Holling) called this type of resilience engineering resilience, which refers to the ability of a system to return to its original state when disturbed, and he introduced this term into ecology, using it to describe the state of the ecosystem. The concept of "adaptive capacity" is also called ecological resilience, which emphasizes the ability of a system to absorb disturbances and to maintain its existence under the influence of problematic factors [6].

1.2. Resilient City

In the 1990s, the academic circle gradually began to summarize the concept of resilience, involving multiple disciplines, such as disaster science, economics, sociology, anthropology, etc., and urban planning was also applied [7]. ICLEI (Local Governments for Sustainability) proposed the idea of "urban resilience" in 2002 [8]. The concept of "resilient cities" emerged, focusing on the response of cities throughout the world to climate change and disaster risk [9]. The system involved is comprehensive, and the factors involved are complex and diverse [8]. Resilience management is a multi-scale project [10]. The existing term "urban resilience" has not been clearly defined [11]. However, there is still much discussion about it. Liao Guixian, a Chinese scholar, summarized engineering resilience in the field of urban planning as reflecting the ability of a system to return to a stable state after a disturbance, with disturbance meaning the threat of destabilization; ecological resilience in this field was summarized as reflecting the ability of a system to adapt to change and reorganize elements in order to maintain balance, thereby increasing its ability to survive in any state with sustainability and flexibility. Faced with uncontrollable factors, it can transform rapidly and adapt to changes [11]. Disturbances should be regarded as opportunities for learning and development. One of these perspectives tends to consider the maintenance or restoration of the system to its original state as the goal, while the other considers the sustainability of the system and the maintenance of its balance as the goal [12].

1.3. Flood Bearing Resilience

Liao also summarized the concept of urban flood bearing resilience as the ability of cities to withstand floods, and as including the abilities of reorganization, minimization of casualties, and maintenance of the current social organization and socio-economic characteristics when infrastructure is destroyed and socio-economic collapse occurs [12]. The main characteristics of flood bearing resilience are summarized as local flood response capacity, the ability to adjust to floods in a timely manner, and subsystem redundancy.

Local flood response capacity is reflected in the ability of a community to adjust and repair in the case of a disaster [13]. The ability to adjust to floods in a timely manner is reflected in the ability to learn from experience. This ability is learned by solving new problems and adapting to new situations in the process of responding to floods [10]. The subsystem redundancy is reflected in the fact that the response to floods can span across multiple system levels, including diverse preparation, mitigation, and response and reorganization methods. Rather than being limited to one system level for coping with floods, the system can actively respond to rain and floods with diversity and flexibility [14], changing the concept of flood control from a traditional reactive approach to a more proactive concept, aiming at resisting floods and restoring the normal way of life, while inspiring society to coexist with floods, considering floods as normal occurrences in the city, and treating each flood as an opportunity to improve the city's capacity for flood bearing resilience, as well as constantly adapting, adjusting, and developing diverse and composite flood response strategies in the process (see Table 1 for a summary of interpretations of urban planning resilience and community resilience to flooding).

1.4. Focus of the Research

From studying the research on flood bearing resilience both nationally and internationally, it can be seen that the focus of the research has mostly been on macroscale areas, and has been theoretical in nature, while relatively little research has been conducted on medium-scale and microscale areas [15]. Also, although some attention has been given to the role of ecological resilience in flood bearing resilience, it has mostly been discussed on large (urban and regional) scales, and the concept of ecological resilience has rarely been incorporated and practically applied, and therefore its operational significance has not been demonstrated. In order to reduce flooding problems that affect the old residential areas on college campuses, this paper presents a study on the improvement of campus flood bearing resilience in small-scale sites (old residential areas of colleges), from a practical perspective. The enhancement of the flood bearing resilience capacity of structures is a topic worthy of in-depth study and exploration, both theoretical and practical, and the study of this subject can be of great value to the campus community. As Chinese economic reform has been in effect for more than 40 years, there has been great improvement in the areas of clothing, food, housing, and transportation among the Chinese population. However, there are still some old residential areas with outdated infrastructure, and these communities face great difficulty in coping with flooding problems. As a part of urban communities, college campuses carry socio-economic functions that are mainly educational but also involve such functions as management, service, security, safety, and stability. Although the college campus population is highly educated and has a high awareness level as to environmental protection issues, problems can still arise with the growth and aging of the campus, such as the construction of settlements with low flood bearing capacity and lack of resilience, which can be affected by various factors including social, economic, and natural factors, causing great inconvenience to the learning and working life of teachers, students, and residents when extreme rainstorms occur. The campuses' subsystems for flood control lack the ability to self-organize and adapt to unpredictable extreme weather. As a result, some college campuses are plagued by flood-related problems. It is difficult and often ineffective to alleviate the disaster by simply renovating and repairing the infrastructure. Furthermore, the difficulty of upgrading construction in an out-of-date college campus environment can hinder the improvement of its flood bearing resilience capacity.

When renovating old residential areas in colleges and universities, in order to increase their flood bearing resistance capacity, problems should be studied from the micro-level, as this approach has been shown to be more practical than a macro-level approach. An effective renovation can improve the quality of life in residential areas, improve community service systems, build modern communities with excellent ecology and beautiful environments, and generally create more joy in the community. This has great importance as colleges and universities are the birthplace of the national core culture, where new technologies and new ideas are created, and they are also important places for the implementation of ideas pertaining to national development. As such, colleges and universities are pillars of the country. Therefore, they are good places to create models that can be applied in other urban settlements for coping with flooding problems, and these models can serve as examples of effective renovations.

Table 1. Interpretation of resilience in urban planning and community flood bearing resilience.

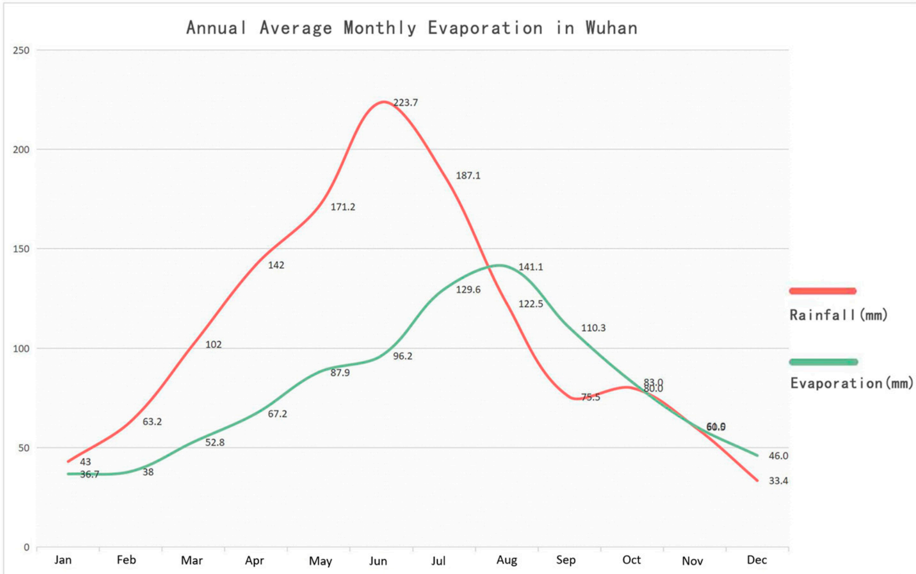
Resilience in Urban Planning	Engineering resilience interpretation	Emphasis is placed on restoring pre-disaster socio-economic conditions and rebuilding the environment [16].
	Ecological resilience interpretation	It is concerned with ever changing ecological conditions and has the complex characteristics of nonlinearity, emergent behavior, uncertainty, and the possibility of accidents [17].
Community Resilience in Handling Floods	Definition	The ability of communities to avoid flood hazards.
	Main feature	Local flood response capacity [18].
		The ability to respond to floods in a timely manner [19].
		Redundancy of subsystems [20].
	Engineering resilience interpretation	The ability to resist floods and treat floods as a threat [20].
	Ecological resilience interpretation	The ability to adapt to floods as an opportunity to learn and continue to develop [21].

2. The Study Area

Wuhan is located at the confluence of the Han Jiang flowing into the Yangtze River, with a quarter of the total area of the city covered in water. As Wuhan's development is based on the characteristic of being partially covered in water, there are higher requirements for the construction of stormwater systems. Heavy rainfall results in a complex situation in which residents must not only deal with the possible flooding of the city and regional stormwater problems caused by flooding, but must also consider water pollution control, ecological landscape restoration, and other issues. Therefore, a multi-objective stormwater management strategy is necessary. There is also a high probability of disaster when extreme weather hits the old residential areas of Wuhan, including the universities, where the damage can be severe. The damage to buildings, circuit blockage, and road flooding caused by rainstorms greatly affects the safety and quality of life of residents of the old residential areas of universities, with older facilities being particularly affected. For example, the dormitory roof in the Huazhong University of Science and Technology collapsed due to serious floor damage caused by heavy rain erosion. Road flooding in Wuhan University was so severe that it was difficult to drive school buses. There was also severe water damage to a classroom in the Hubei Institute of Fine Arts. In the China University of Geosciences, Wuhan, a circuit jack was damaged by heavy rain. Many colleges and universities in Wuhan are facing safety problems due to rainstorms. We chose the east district of the China University of Geosciences, Wuhan, as the study area for the campus renovation design for the improvement of flood bearing resilience capacity. This section contains information on the study area. It describes the general situation of the project site and discusses the problems caused by heavy rainstorms in CUG, Wuhan.

2.1. Overview of the East District of the CUG, Wuhan

Wuhan is located in a subtropical monsoon climate zone and has a hot and humid summer and a drier autumn and winter. Rainfall is concentrated in June and July. The average monthly evaporation and rainfall are listed in Figure 1 [22].



Annual Average Daily Rainfall Intensity Distribution in Wuhan

Figure 1. List of annual monthly rainfall and evaporation in Wuhan. (Picture produced by the authors).

The east district of the CUG, Wuhan, covers an area of approximately 90,000 square meters, mainly composed of teaching buildings, graduate student dormitories, family quarters, sports fields, small parks, ponds, etc. The green areas in this region include approximately 45,586 square meters, accounting for 50.6% of the overall area. However, these green areas are composed of vegetation along roadsides, green lands, and parks, while the rest of the area is paved. Due to excessive impervious pavement and a simple drainage system, a certain degree of water accumulation occurs during heavy rain periods, particularly in June and July, resulting in significant rainwater problems in the east district of the campus. The existing drainage in this area is mainly through open ditches, which cannot withstand the heavy rains in Wuhan during the summer. The rainwater flows directly into the sewage system without use of the rainwater system to purify and storage it, causing a waste of resources.

2.2. Problems Caused by Heavy Rain in the East District of the CUG, Wuhan

A survey has revealed that the east district of the CUG, Wuhan, faces the following issues: (1) The hard slope and lack of bank protection in the koi pond has resulted in the erosion of soil into the water body and the blockage of the ecological diversity channel, leading to a lack of natural purification ability in the water in the pond [23]. (2) Water quality pollution has become a problem, as the water in the koi pond is green and turbid with low visibility and an unattractive appearance. (3) Poor drainage capacity: due to the low terrain and weak drainage capacity of the pipelines in the East District, there is severe water accumulation in some areas during the rainy season, causing negative impacts on the travel and daily life of teachers and students. (4) The koi pond's edge and surrounding areas mostly use impermeable paving, resulting in weak rainwater infiltration. Based on the analysis in Section 2, planning vision and analysis for the site can be seen in Figures 2 and 3.

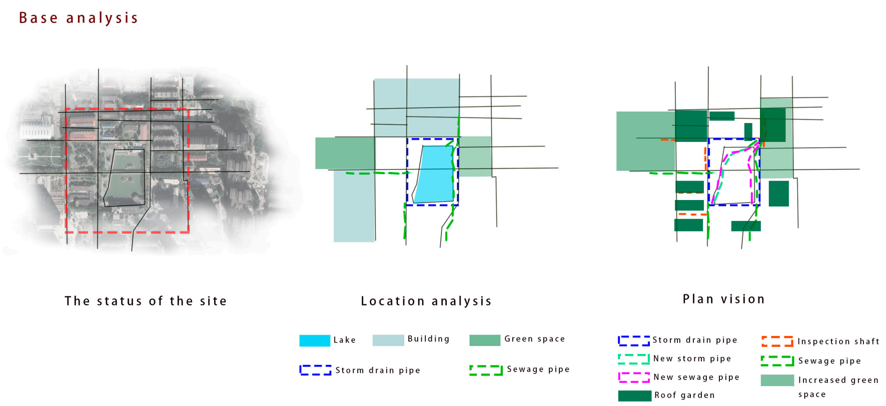


Figure 2. Renovation design concept for the east district of the CUG, Wuhan (picture drawn by the authors).

Figure 3. The koi pond and its surrounding areas in the east district of the CUG, Wuhan, before renovation (picture taken by the authors in April 2015).

3. Methods

According to the above analysis, the third chapter puts forward a vision for building a resilient campus. In combination with the previous review on resilience, we propose a plan for the building of a resilient campus and define the goal of this renovation as the improvement of the capacity of the campus for dealing with stormwater problems. Based on this goal, we have designed our research methods in order to carry out the renovation of the campus. The main methods used in this study were qualitative analysis, empirical research, literature research, and observation, with the intention of visualizing and expressing the improvement of campus flood bearing resilience from the perspective of ecological resilience. We also clarified the elements of the system, so that the semi-artificial ecosystem and artificial ecosystem can actively cooperate with the natural ecosystem and help solve stormwater problems.

3.1. Building A Resilient College Campus

We thought it necessary to change the mindset that promotes constant updating and repairing infrastructure to resist flooding [24] and find it preferable to promote the self-adjustment and recovery of the natural system. We should also respond to flooding problems through the synergy of multiple system layers, and we believe these methods can improve the flood bearing resilience capacity of the college campus.

Keeping this goal in thought, we should also follow the principle of ecology, respecting the ecological functions of landscape plants, taking into account their role in climate regulation, air and soil purification, and water conservation, and we should strive to meet the ecological needs of the campus landscape while beautifying the campus environment and providing people with a pleasant aesthetic experience.

We should follow the principle of biodiversity, selecting native plants, forming a diverse landscape of zonal plant communities, and making a design that fits the local natural conditions and reflects the natural landscape characteristics.

We should also follow the principle of high efficiency, reducing the consumption of resources and energy consumption, and conserving financial and material resources.

We also intend to follow the principle of localization, respecting the topography and maintaining the integrity of the site, respecting nature, protecting the environment, having the smallest possible impact on the natural environment, achieving harmonious coexistence between humans and nature, and achieving sustainable development.

The objective of improving college campus flood bearing resilience capacity should also be clarified. When facing the problem of rainwater flooding, the safety, security, and property of the people should be a top priority, while protecting vegetation and enhancing the speed of rainwater discharge, the storage capacity of the college campus, and the infiltration capacity of rainwater. Reducing soil erosion, extending the life of rainwater facilities, and preserving water resources should also be prioritized. The improvement of the flood resilience capacity of college campuses should also aim to preserve the beauty of the environment. Based on these goals, we should fully respect and protect the natural conditions of the original college campus site. We should use low-impact development and low-cost, simple to implement, and sustainable methods that promote the interaction of the various components of the ecosystem.

3.2. Solution to the Problem

Ecosystems refer to the natural space where organisms and the environment, together, form a cohesive whole, and there are relationships between them that affect and constrain each other. Three types of ecosystems are natural ecosystems, semi-artificial ecosystems, and artificial ecosystems [25]. Among these, semi-natural ecosystems, which can affect the natural environment through human activities, play both natural and artificial roles. Artificial ecosystems, which are ecosystems formed by humans through a series of social activities with the intention of sustaining human survival and development, can reflect the state of cyclic development of human activities, natural ecology, and socio-economic conditions and are important in assessing the health of the ecosystem. From the perspective of prioritizing the improvement of the flood bearing resilience capacity of universities, it is of key importance to study how to integrate semi-natural ecosystems and artificial ecosystems into natural ecosystem operation and how to promote the synergy of each ecosystem to cope with college campus rainfall flooding in order to improve flood bearing resilience.

We categorize the environmental factors that can affect the ability of college campuses to deal with flood problems in both semi-artificial ecosystems and artificial ecosystems. The content of the college campus semi-natural ecosystem includes ponds, green spaces, etc., while the content of the artificial ecosystem includes roads, building spaces, outdoor hard pavement activity spaces, and storm-flood facilities. When extreme rainstorm weather disasters occur, these ecosystems can cooperate in order to help cope with flooding problems [26].

3.2.1. Semi-Artificial Ecosystem Renovation

Semi-artificial ecosystems on college campuses can include the water pond, green space, etc. Some ponds on old college and university campuses are neglected, not properly cleaned and maintained, and the water is murky. The artificial hard lake bank and slope of the college campus ponds cause the soil and water to be separated, which cause the organisms and microorganisms in the water to be unable to reach the land. Biological channels in the ecotone are blocked, leading to the deterioration of the water quality and the decline of the natural purification capacity of the pond. College campus water serves both to beautify the space and to regulate microclimates. Wetlands can be created to keep down runoff, store flood water, and prevent drought. Aquatic plants should be planted in the pond. Plants with significant effects on purifying water and improving water quality should be selected [27], and they should also have strong stress resistance. A properly maintained pond can contribute to the development of stable water ecosystems. On college campuses, there are many educational buildings and office buildings occupying a large area of land. The permeability of hard pavement is insufficient and the green space is limited which, together, cause a large portion of the college campus to lack sufficient drainage. Additionally, the plant configuration is relatively simple. In the face of sudden flooding problems, the water tends to accumulate, affecting college campus traffic and causing safety risks. One method for increasing the flood bearing resilience capacity of the campus is to increase the green area percentage and improve the level of leachability [28]. This can be done in the following ways: (1) Update the college campus plant configuration structure, favoring a more vertical type of structure that can buffer the impact of rain on the surface, reducing instantaneous surface runoff and delaying the formation of the flood peak, and planting species of plants that are conducive to improving soil structure and improving soil permeability. (2) Increase rainwater infiltration in the green area, roofed green area, and pond wetland area. In addition, the green area can be increased by using permeable grass-planting bricks in the parking lot. (3) Build rain gardens that can transform the original green space on the college campus into a concave green space. In addition, make shallow vegetation ditches on both sides of the road. These can play a role in reducing rainwater flow rates and controlling rainwater runoff.

3.2.2. Artificial Ecological System Update

The artificial ecological system on the college campus includes roads, parking lots, outdoor activity spaces, building spaces, rainwater collection facilities, drainage system infrastructure, etc. The hard pavement on the college campus occupies a large amount of soil space. The permeability of the paved area is poor, with a low infiltration rate of rainwater, resulting in the waste of rainwater resources and lessening the utility of the site [29]. To address this issue, it is necessary to promote the infiltration of rainwater and restore the natural cyclicity of rainwater. This can improve the flood resistance of the land. The proportion of rainwater permeable areas on the college campus should be increased, by (1) replacing hard pavement materials on the college campus with permeable materials and using permeable base soil, allowing the water to effectively infiltrate the surface and reach the lower soil through the permeable filtration path in the face of flooding; (2) using building roof spaces for roof gardening, allowing for the gradual infiltration of water into the soil through plants and permeable soil, and collecting and purifying rainwater that can be used for college campus firefighting and garden watering [30]; and (3) updating the rainwater collection system and rainwater purification system to reduce surface runoff, increase rainwater utilization, and reduce the waste of rainwater resources [31].

3.2.3. Summary of Strategies for Improving the Flood Bearing Resilience Capacity of College Campuses

The contents of Sections 3.2.1 and 3.2.2 are related to reducing the runoff velocity, the instantaneous surface runoff, and the impact of artificial ecosystems on rainwater circulation. It is necessary to raise the proportion of floodable areas, enhance rainwater infiltration capacity and increase the ability of rainwater collection and purification, in order to improve the flood bearing resilience capacity of the college campus. The semi-artificial ecosystem and the artificial ecosystem, after transformation, should play key roles in solving rainwater problems, and more attention should be given to the circulation of rainwater in the natural ecosystem. The three types of ecosystems should not be separated but should work in coordination in solving the rainstorm problem. Figure 4 shows the method map of our idea. And Table 2 shows strategies for improving the flood bearing resilience capacity of college campuses.

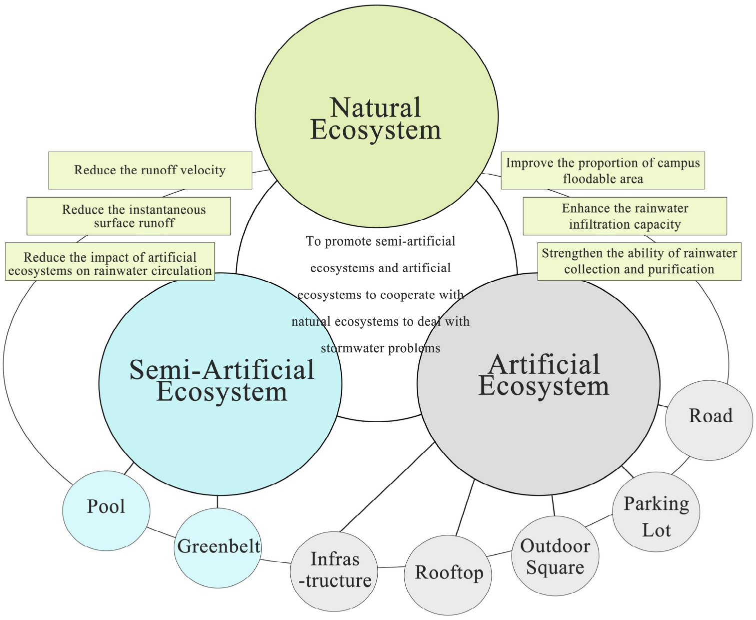


Figure 4. Method map (picture drawn by the authors).

Table 2. Design strategy for college campus renovation of metro university to increase flood bearing resilience.

The Ecological System	Strategy	Specific Application Site	Specific Strategies for Building Resilient College Campuses
Semi-artificial ecosystem	Improve the greening rate of the college campus	Koi pond	① Plant aquatic plants and release aquatic animals to create wetland. ② Add cutoff wall to prevent water pollution caused by external and internal infiltration of pool water.
		Green space	① The configuration form of arbor-shrub-herb enriches the vertical structure level [27]. ② Increase the accessible landscape, and increase the leachable area integrating greening, rainwater retention, rest, and other functions. ③ Rain garden; concave green space; and vegetation gully.
Artificial ecosystem	① Use permeable paving materials; ② The roof garden; ③ Update rainwater collection system and rainwater purification system.	Road	Vegetation gully
		Parking lot	① Use materials with strong water permeability. ② Buried water collection perforated pipe under the soil to collect rainwater.
		Hard outdoor playground	① Use materials with strong water permeability.
		Building roof	① Plants with high porosity roots, low density, and erosion resistance were selected. ② Waterproof material with root separation function [30]. ③ The storage and drainage disk is combined with the substrate layer and the moisture layer of the sintered soil. ④ Planting cold-tolerant, drought-resistant, native plants [32].
		Rainwater collection and purification facilities	Update and repair the rainwater collection and purification facilities [33].

4. Case Study

4.1. Overview

Renewal Design for the East District of the CUG, Wuhan, for the Improvement of Flood Bearing Resilience

The fourth chapter is the most practical part of this paper. We have put forward a series of problems caused by flooding in the CUG, Wuhan. We then elaborate on the strategy and method of college campus renovation for the improvement of flood bearing resilience, focusing on two aspects: the semi-artificial ecosystem and the artificial ecosystem.

4.2. Transformation of Semi-artificial Ecosystems

4.2.1. Updating the Design of the Koi Pond

(1) Construction of a Wetland Landscape for the Koi Pond

A wetland landscape should be constructed for the koi pond through the planting of vegetation and the introduction of aquatic animals. Plants such as *typha angustifolia*, *Phragmites australis*, and *Oenanthe javanica* (*Blume*) *DC.*; floating plants such as *Eichhornia crassipes* (*Mart.*) *Solms* and *Lemna minor*; and submerged plants such as *Myriophyllum verticillatum* L. and *Potamogeton wrightii Morong* should be included (see Figure 5 and Table 3 for the updated and transformed design plan for the koi pond). The photosynthesis and improvement of the underwater light conditions can increase the amount of dissolved oxygen and avoid the production and escape of harmful gases such as H2S. It can also effectively curb the malignant proliferation of algae. Different fish species are configured according to their different habits. Carp and crucian carp are bottom feeders, mainly feeding on insect larvae, fragments of aquatic higher plants [34], debris, and algae. Largemouth bass are upper-layer-dwelling fish, feeding on planktonic plants. These fish species are suitable for introduction into the koi pond.

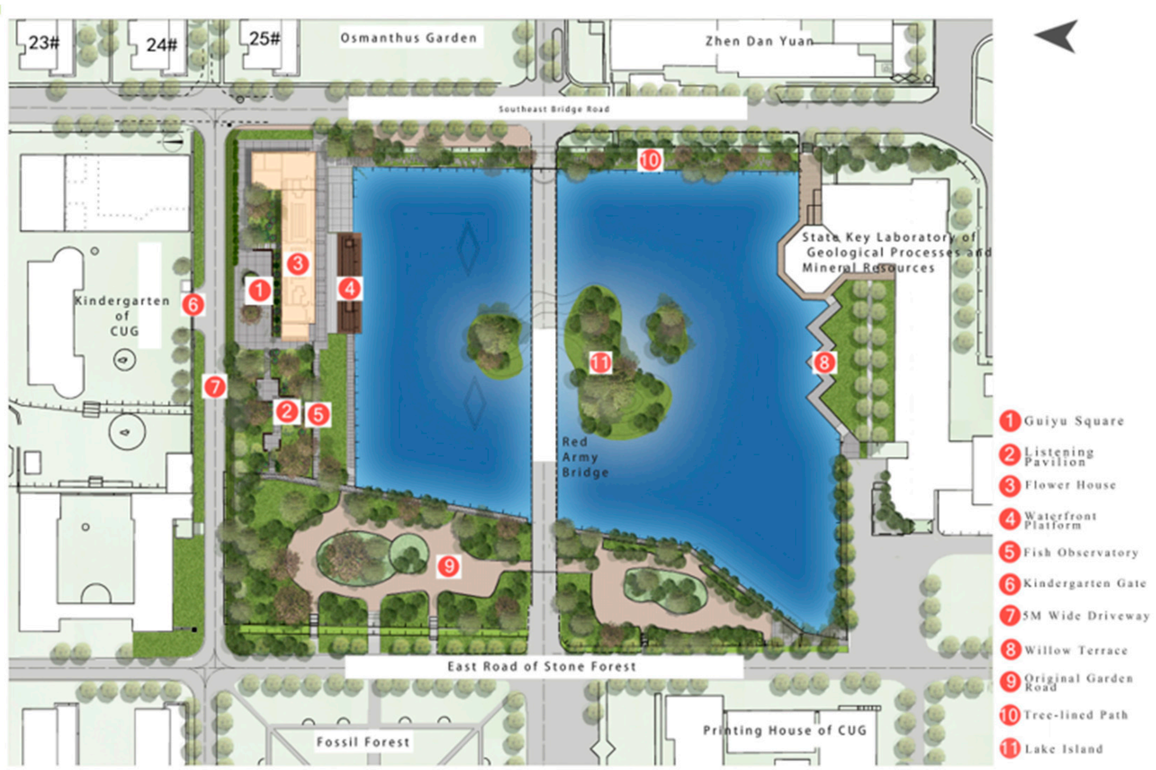


Figure 5. Design plan for the koi pond in the east district of CUG, Wuhan (picture drawn by the authors).

Table 3. Greening plant configuration table.

Different Regions	Recommended Plant				Function
Koi Pond Wetland	Alternating Dry and Wet Areas	Shallow Water Area	Deep Water	Lake Island	Build biodiversity, regulate microclimate, beautify environment, store rainwater, purify rainwater, reduce surface rainwater runoff, slow down water flow speed, and increase the area of the college campus that can absorb rainwater
	<0.3 m	0.3–0.6 m	0.9–2.5 m	*Fatsia japonica* ((*Thunb.*) *Decne. & Planch.*), *Loropetalum chinense* ((*R.Br.*) *Oliv.*), *Musa basjoo* (*Siebold ex Miq.*), *Lagerstroemia indica* (L.), *Ligustrum × vicaryi* (*Rehder*), *Thalia dealbata* (*Fraser*), *Acer palmatum* (*Raf.*), *Gardenia jasminoides* (*J.Ellis*), and *Photinia serrulata*	
	Amphibious plants: Iris tectorum (*Maxim*), *Typha orientalis* (*C. Presl*), *Lythrum salicaria* (L.), *Persicaria hydropiper* ((L.) *Delarbre*) , and *Acorus calamus* (L.)	*Water plants: Typha angustifolia* (L.), *Phragmites australis* ((*Cav.*) *Trin. ex Steud.*), *Nelumbo nucifera* (*Gaertn.*), and *Oenanthe javanica* ((*Blume*) *DC.*)	*Submerged plants: Myriophyllum verticillatum* (L.) and *Potamogeton distinctus* (*A.Benn.*) *Floating plants: Nelumbo nucifera* (*Gaertn.*), *Eichhornia crassipes* ((*Mart.*) *Solms*), and *Lemna minor* (L.)		
Building Roof	Herbaceous	Shrub	Trees		
	Hemerocallis fulva ((L.) L.) *Lonicera japonica* (*Thunb.*), *Iris tectorum* (*Maxim*), *Hydrocotyle vulgaris* (L.), and *Canna indica* (L.)	*Jasminum nudiflorum* (*Lindl.*), *Lagerstroemia indica* (L.), *Hydrangea macrophylla* ((*Thunb.*) *Ser.*), and *Hibiscus syriacus* (L.)	*Prunus cerasifera* (*Ehrh.*), *Camellia japonica* (L.), and *Acer palmatum* (*Raf.*)		
Rain Garden	*Lonicera japonica* (*Thunb.*), *Aspidistra elatior* (*Blume*) *Hydrocotyle vulgaris* (L.) *Juncus effusus* (L.), and *Canna indica* (L.)	*Aspidistra elatior* (*Blume*) *Buxus megistophylla* (*H.Lév.*) and *Euonymus japonicus 'Aurea-marginatus'*	*Pterocarya stenoptera* (*C.DC.*), *Acer buergerianum* (*Miq.*), *Cinnamomum camphora* ((L.) *J.Presl*), and *Bischofia polycarpa* ((*H.Lév.*) *Airy Shaw*)		
Vegetation Gully	*Lonicera japonica* (*Thunb.*), *Hemerocallis fulva* ((L.) L.), and *Juncus effusus* (L.)	*Musa basjoo Siebold ex Miq.* and *Lagerstroemia indica* (L.)	*Acer buergerianum* (*Miq.*) and *Chimonanthus praecox* ((L.) *Link*)		
Other Green Space	*Aspidistra elatior* (*Blume*) and *Lonicera japonica* (*Thunb.*)	*Buxus megistophylla* (*H.Lév.*), *Phoenix dactylifera* (L.), *Gardenia jasminoides* (*J.Ellis*), *Lagerstroemia indica* (L.), *Photinia serrulata*, and *Musa basjoo Siebold ex Miq.*	*Cinnamomum camphora* ((L.) *J. Presl*), *Pterocarya stenoptera* (*C.DC.*), *Platanus × acerifolia* ((*Aiton*) *Willd.*), and *Cinnamomum jensenianum* (*Hand.-Mazz.*)		

(2) Transformation of Hardened Shore for the Koi Pond

The shore surrounding the koi pond is a hardened shore, and due to long-term erosion by rain, there are gaps between the boulders that form the edge, leading to seepage of water outside the pool and infiltration of rainwater and sewage from the surrounding rainwater and sewage pipes, causing water pollution. To improve the water quality and enhance the appearance of the college campus landscape, a 200 mm reinforced concrete anti-seepage wall was added outside the original shore to solve the problem of water pollution caused by seepage inside and outside the pool (see Figures 6–8 for relevant cross-sectional images of the koi pond and ecological slope sections).

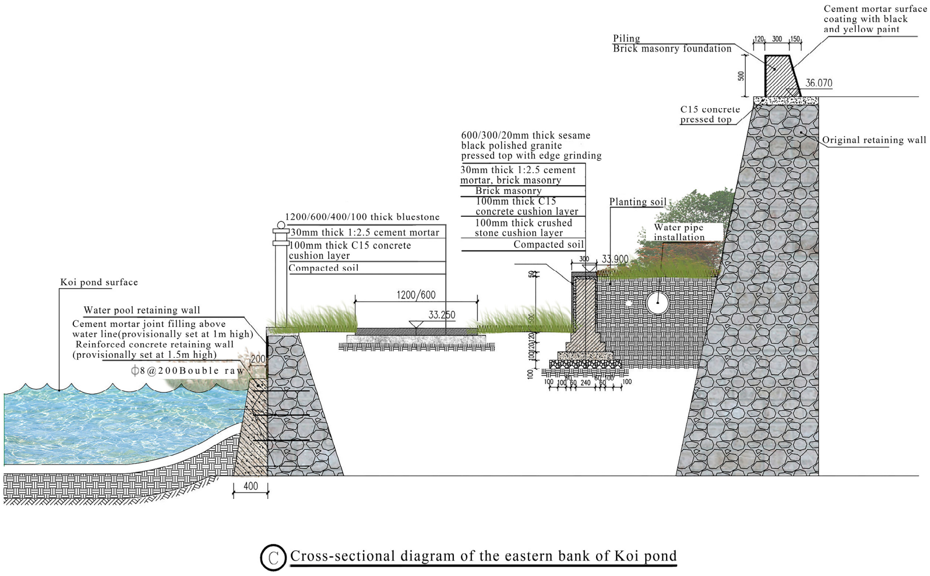


Figure 6. Trail section on the east side of the koi pond (picture drawn by the authors).

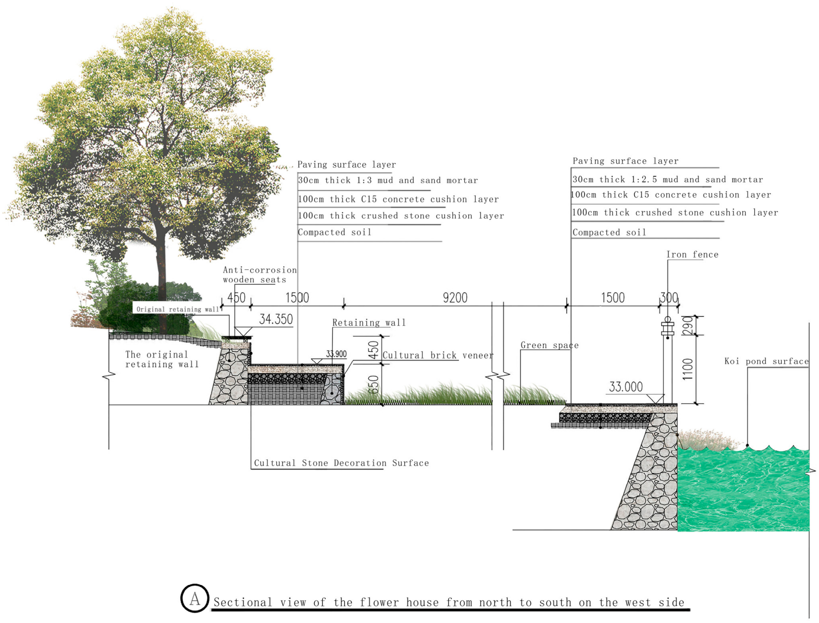


Figure 7. Sectional view of the flower house from north to south on the west side (picture drawn by the authors).

4.2.2. Green Space Transformation

In the residential area of the east district of the CUG, Wuhan, there are some green spaces provided for pedestrians, including some small parks (such as Zhang Park and Gui Park, etc.). Transforming these green spaces into rain gardens [35] not only improves the college campus landscape, but also purifies rainwater, slows down water flow, and extends rainwater storage time [36]. Due to the erosion effect caused by rainwater, soil loss can occur, so it is important to stabilize soil in green spaces with a high slope or where rainwater is concentrated and erosion occurs. In plant selection, the following points should be followed: (1) Local tree species native to Wuhan should be used, as they have strong resistance to diseases and pests and are easy to maintain. (2) Plants with ornamental value and fragrance should be selected, so as to attract insects such as bees and butterflies and create biodiversity. (3) Plants with strong vitality and well-developed roots should be selected. For example, trees such as *Acer palmatum* (*Raf.*), *Acer buergerianum* (*Miq.*), *Cinnamomum camphora* ((L.) *J.Presl*), and *Bischofia polycarpa* ((*H.Lév.*); shrubs such as *Aspidistra elatior* (*Blume*), *Buxus megistophylla* (*H.Lév.*), *Euonymus japonicus 'Aurea-marginatus'*, etc.; and herbaceous plants such as *Lonicera japonica Thumb*, *Hydrocotyle vulgaris* (L.), *Juncus effusus* (L.), *Canna indica* (L.), *Iris tectorum* (*Maxim*), etc. (See Table 3 for specific plant configurations and see Figure 9 for a semi-artificial system update with design illustration).

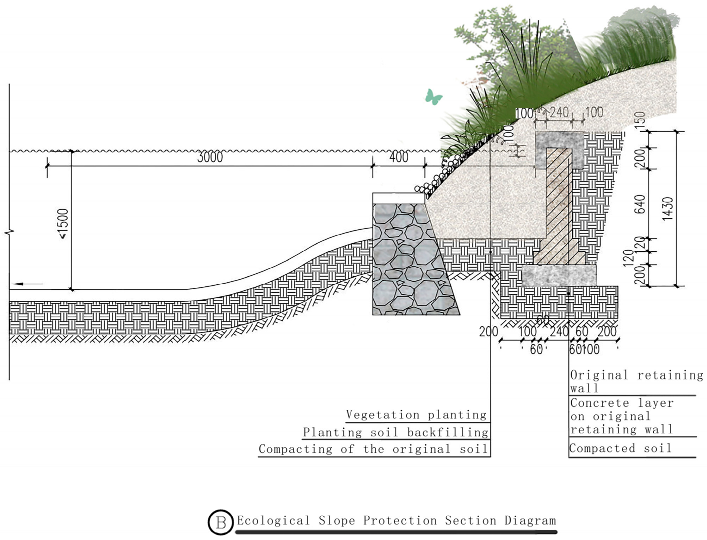


Figure 8. Sectional view of the ecological slope of the greenhouse (picture drawn by the authors).

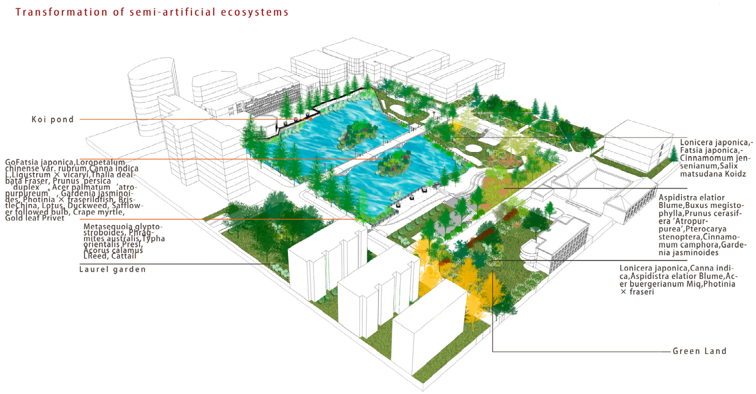


Figure 9. Schematic diagram of semi-artificial ecosystem transformation (picture drawn by the authors).

4.3. Transformation of Artificial Ecosystems

4.3.1. Updating and Transformation of Roads, Parking Lots, and Outdoor Activity Spaces

(1) Roads

Shallow grooves with vegetation should be made on both sides of pedestrian or vehicular roads so as to utilize surface plants and soil to intercept and purify rainwater pollutants. When rainwater enters a shallow groove, the pollutants are removed through the combined effects of filtering, permeation, and biodegradation. The roads should also be changed from ordinary concrete to permeable concrete.

(2) Parking Lots

The parking spaces within the design scope use concrete with poor permeability and should be changed to permeable grass bricks in order to increase the greening area. The base should be made of concrete with good permeability to promote water infiltration, and perforated pipes should be buried in the soil to collect rainwater and discharge excess water to nearby reservoirs or ponds. In addition, the ground covering of outdoor hard-surfaced activity spaces should also be changed to permeable materials in order to increase rainwater infiltration and reduce surface runoff.

4.3.2. Building Roof Transformation

There is a large, old residential area in the east district of the CUG that includes student dormitories and teacher apartments. The drainage system in the residential area has mostly hard-surfaced downspouts, which cause flooding during the rainy season. By planting a rain-watered roof garden (green roof), the amount of green area on the campus can be effectively increased, rainwater can be more effectively collected, and the houses can be cooled in summer and kept warm in winter, improving the ecological environment of the college campus and the water storage and drainage situation in the area. The old-style houses in the east district of the CUG generally have low roof load capacity and are only suitable for lightweight roof gardening, and the following points should be noted: (1) The substrate used for roof garden planting should be selected to contain materials that have high porosity, low density, are resistant to erosion, and are suitable for use in cultivation. Volcanic stone and zeolite are some examples, but currently, sintered stone is widely used due to its qualities of efficient drainage and rapid water discharge even in high moisture content. Additionally, plants in the later stages of growth are less prone to root rot. (2) For the construction of a roof garden, waterproof materials with root-barrier functions, such as VEDPLAN-BR-bamboo root penetration green roof waterproof coil should be used. (3) The roof should be constructed in a way that prioritizes water storage and drainage. Currently, a combination of water storage and drainage trays with sintered soil and a moisture retention layer is widely used. (4) Plants should be selected according to local climate and natural conditions, using locally grown, hardy, drought-resistant, evergreen, and shallow-rooted plants that are adapted to the soil type and thickness used. Table 3 shows the plant configuration.

4.3.3. Infrastructure Update

In the koi pond, rain and sewage are diverted to the north, west, and south sides. The rain and sewage pipelines on the north and east sides are replaced with DN800 socket-type cement pipes, replacing the original pipelines. On the east side of the koi pond is a row of dense cypresses, the north side has a flower house, and there is a main gas pipeline near the pond on the south side. Two DN800 pipes are set up east of the Red Army Bridge for the diversion of rainwater and sewage. They extend from the east side of the water tank to the east, between the flower house and the newly built nursery school building, to the west of the pond, and connect to the original DN800 pipeline. Meanwhile, a new DN800 socket-type cement pipe is installed next to the original DN800 pipeline (inside the pond) and connected to the weir box on the south side of the water tank as a sewage pipeline, and the original pipeline is used as a rainwater pipeline for rain and sewage diversion. Rainwater is collected on the north side of the koi pond. A filtering planting tank is set up under the green belt and installed under the trees, forming a biological retention area. Runoff can be directed to the planting tank, reducing surface runoff, and filtering and purifying it. The rainwater collection system in the koi pond area of the college campus can be continuously used. After the rainwater is treated on the subgrade, it can be used for flushing vehicles, watering roads, or gardening in the surrounding area. An initial rainwater diversion well is set up in the water tank, and the initial rainwater is collected and disposed of through the rainwater pipeline network. After being treated by the sewage treatment system, it is sent to the college campus gardening system and can be used as a water source for gardening and landscaping (reform plan of artificial ecological system, see Figure 10).

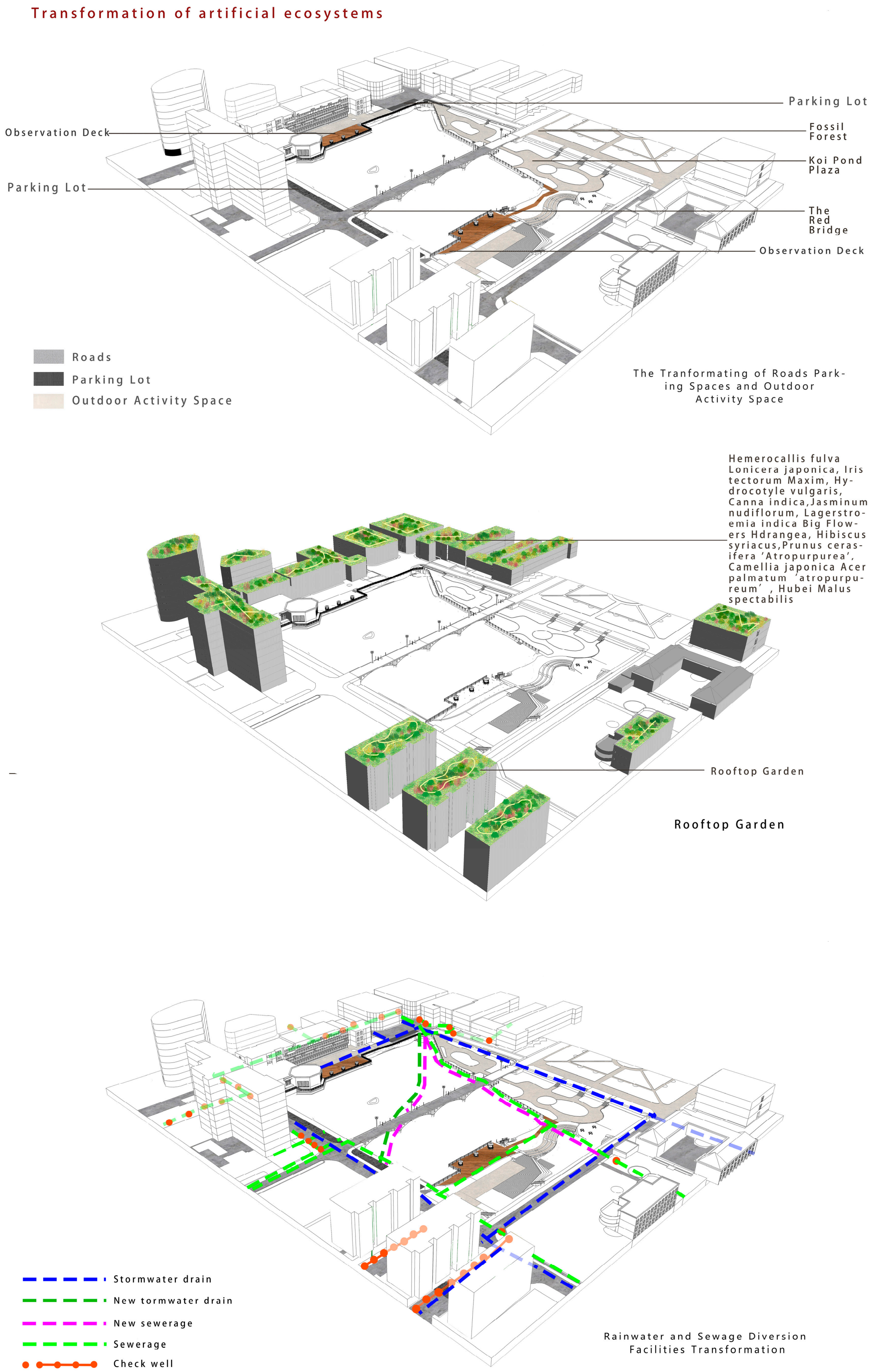


Figure 10. Schematic diagram of artificial ecosystem transformation (picture drawn by the authors).

5. Results and Discussion

5.1. Results

Using the renewal design for the koi pond and its surrounding areas in the east district of the CUG, Wuhan, as a practical example, we applied the idea of coordinated operation among various systems with the natural ecological system participating to the water cycle operation. The combination of strategies and practical design examples provides ideas and references that can be used to update other universities' outdated residential areas in order to improve their flood bearing resilience. We analyzed elements that affect campus flood bearing resilience in semi-artificial ecosystems and artificial ecosystems and proposed updated design strategies that incorporate semi-natural ecosystems and artificial ecosystems into the operation of natural ecosystems to promote collaborative operations between the systems, in which the interacting ecosystems jointly cope with rainstorm disasters across multiple system levels, resulting in enhanced local flood response capabilities. This combined multi-level approach can improve flood bearing resilience, increase personal property safety for campus residents, protect campus vegetation, reduce soil erosion, increase campus rainwater discharge velocity, increase storage capacity and infiltration capacity, as well as improve campus environmental quality and aesthetics.

There is limited space on campus for updating designs, so our design mainly relied on building rooftop gardens and lake islands to increase regional green space (see Figure 11 for results). The roof gardening area is 2106.6 m^2. The green space area built from lake island silt is 1137 m^2. Parking spaces are paved with grass bricks which, after conversion, create a green area of 78.95 m^2 [37].

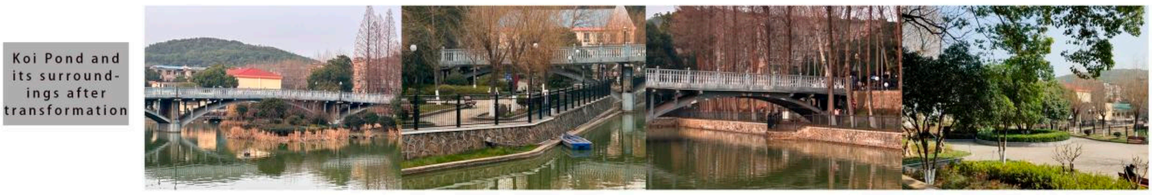


Figure 11. The koi pond and its surrounding areas in the east district of the CUG, Wuhan, after renovation (photo taken by the authors in February and March 2023).

The total green area around the koi pond increased by 3322.55 m^2, making the total green area grow from 45,586 m^2 to 48,908.55 m^2, resulting in an increase in this region's green coverage rate from 50.6% to 54.3%. In terms of plant design, a more diverse vertical structure was implemented, and more plant species were added. While enhancing its beauty and appreciation value, it also has the function of soil protection and water purification. Among the changes, the wetland in the koi pond's and the planting design using lake island plants are most important for purifying the koi pond's water.

In addition to the building area, 4215.41 m^2 of outdoor paved area and 5782 m^2 of road surface are to be replaced with permeable materials. The ordinary concrete on the road will be replaced with permeable concrete. The material of the outdoor paving area will be replaced with imitation stone ceramic permeable bricks, which possess a range of impressive qualities, including water and air permeability, a porosity rate of 20–30%, excellent water storage capacity, and the ability to filter and conserve water. When the pavement collects rainwater, it can reduce surface runoff, delay the occurrence time of extreme surface runoff in campus areas, regulate surface humidity and temperature, and alleviate the urban heat island effect. Its permeability rate is $\geq$31 L/(h·m^2), its permeability coefficient is $\geq 2.0 \times 10^{-2}$ cm/s, and the amount of rainwater the outdoor paved area can drain per hour in this area is 130,677.71 L.

5.2. Discussion

Ecological improvement is a significant aspect of the "14th Five-Year Plan" of the country, and the updated design of the college campus rain and flooding problems should meet the needs of national development, with the goal of benefiting the people. However, the circulation operation between various ecosystems is extremely complex, difficult to fully grasp, and constantly changing as a whole. Therefore, we should not only focus on improving the ability of semi-artificial and artificial ecological systems to cope with rainwater and floods through updating system elements but also pay attention to optimizing and perfecting disaster response processes and risk management systems on campuses [38]. This involves multiple subjects including groups, organizations, residents in campuses, etc. [39], which requires not only rich knowledge reserves and well-trained emergency response capabilities for responding to campus disasters, but also taking into account the view of residents, listening to the professionals, and applying subjective initiative when facing disasters.

In addition, more attention should be paid to observing changes in campus environments after strategy updates are implemented such as flood retention status as well as teachers', students', and residents' living conditions. We should track possible and existing problems in the campus environment in real time while coordinating relationships among different ecosystems in order to adjust campus flood control strategies accordingly. From another perspective, based on coping with flood issues at a subsystem level, we can further design resilience enhancement plans for regional life circle units by refining them step by step according to service scope concepts such as the 15 min rescue circle, 10 min rescue circle, and 5 min rescue circle distance, so that problems can be efficiently addressed at different levels. This is also a topic which is worth continuing discussion and research.

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