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Urban Informal Settlements as sites for Green Infrastructure: Regenerating Dayouzhuang and Saoziying Urban Villages in Beijing

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URBAN INFORMAL SETTLEMENTS AS SITES FOR GREEN INFRASTRUCTURE: REGENERATING DAYOUZHUANG AND SAOZIYING URBAN VILLAGES IN BEIJING

A Master’s Project Presented

By

Feiqiang Tong

Submitted to the Graduate School of the University of Massachusetts Amherst in partial fulfillment of the requirements for the degree of

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URBAN INFORMAL SETTLEMENTS
AS SITES FOR GREEN INFRASTRUCTURE:
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Abstract

Urban villages are the primary form of urban informal settlements in China. They emerge from the ongoing process of extensive rural-to-urban migration. While urban villages provide more readily available and affordable housing options for new urban migrants, their overloaded population and poor living environment have become a problem in the city. The existing official solution of urban villages is to remove them and to replace them with new developments. This solution takes a long time to complete and neglects the social role of urban villages in the city.

This project focuses on solving the inland flooding problem that occur regularly in the summer monsoon season in the urban villages of Beijing, and proposes to use a green infrastructure (GI) approach, instead of conventional infrastructure, to control and manage stormwater on-site more effectively and in an environmentally-friendly way. By comparing the urban villages in Beijing with informal settlements in Mumbai and Sao Paulo, this project recognizes the specific physical environment in each city and evaluates their upgrading plans from a landscape architect's point of view. Learning from that comparative assessment, the project selects two adjacent urban villages, Dayouzhuang and Saoziying in Beijing. Based on the site analysis of those two villages, the project study creates a toolbox of GI techniques and proposes a stormwater management system with appropriate GI tools from the toolbox. In terms of the different degrees of intervention, two alternatives are created. One is a limited removal of existing buildings with lower cost; another is a medium-level removal with higher cost. By proposing GI alternative in the urban villages, the project gives a prospective view of improving urban hydrology by regenerating urban villages with GI techniques in Beijing.
1. Introduction

This chapter will introduce the definition of the urban village, and the issues associated with it. This chapter will also identify the major purpose of the project, the principal research questions, the research goals and objectives, and the organization of the project. At the end, this chapter will introduce the scope of the research in terms of limitations and delimitations of the project.

1.1 Purpose and Significance

There are now approximately one billion people living in informal settlements worldwide, a number expected to double by 2030 (United Nations Habitat, 2003). Urban informal settlements show a very different type of urban landscape from the urbanized city. They are marked by the high ratio of migrant population, high building density, and inadequate infrastructure (David, 2006; United Nation Habitat, 2003; Zheng, Siqi etc., 2009).

In the urbanization process, urban villages are often the shelters of rural migrants when they come for more job opportunities but cannot afford the high rent rates in the city (Wang, Wang etc., 2009; Zheng, Siqi etc., 2009). The coming of urban migrants meets the demand of the urban development for a considerable pool of laborers (Zheng, Siqi etc., 2009).

The ongoing actions on upgrading urban villages are dominated by political and economic factors (Wang, Wang etc., 2009; Zheng, Siqi etc., 2009). The municipal governments remove urban villages and rebuild with new developments. This solution takes a long time to complete and underestimates the current housing demands of migrant residents (Gao, Dong etc., 2006). The villagers and migrants have to suffer the poor environmental quality in urban villages before the new developments build. Recently, discussions have emphasized the role of urban villages in the
process of city development (Zheng, Siqi etc., 2009). Some authors argue that the emergence of urban villages is inevitable, and that the local governments and decision makers should keep the contributions of urban villages, but focus on solving the problems. This change represents a calling for more short-term, directly effective regeneration in urban villages.

One of the main environmental problems in urban villages is inland flooding, which has been widely mentioned in recent years, especially in Beijing. The major reason for the inland flooding is the high impervious paving percentage and the fragmentized drainage pattern, caused by the vertical spontaneous building developments. The highly-developed urban environment does not support the natural stormwater cycle. Another reason for inland flooding is that the aged utilities for drainage are not adequate for the current usage. Also, climate change has affected the intensity of precipitation; the daily precipitation summer in 2012 reached a new historical high. The detailed analysis on the causes of inland flooding will be illustrated later in the following chapters.

This project, from a landscape architect's perspective, acknowledges the existence of urban villages, and attempts to find a key for sustainable management of the inland flooding issue in Beijing’s urban villages. It proposes green infrastructure (GI) implementation as the short-term upgrading solution, supplementing the conventional infrastructure with managing the stormwater more ecologically. This project attempts to create a GI toolbox, which is composed of a series of GI techniques that suit the site conditions, and then create GI masterplan alternatives based on the toolbox.

This will provide a systematic management of stormwater that also adapts to the complicated environment, reduces the runoff, supplements the existing drainage utilities, and improves the natural cycle of stormwater. Besides, compared with the conventional infrastructure, the green infrastructure has the following advantages (Table1-1).
**Table 1-1 Comparison of Conventional Infrastructure and Green Infrastructure (Ahern, 2007)**

<table>
<thead>
<tr>
<th>Conventional Infrastructure</th>
<th>Green Infrastructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expensive to build and maintain</td>
<td>Lower cost</td>
</tr>
<tr>
<td>Energy intensive to operate</td>
<td>Energy conservative, or neutral</td>
</tr>
<tr>
<td>Contributes to greenhouse emissions</td>
<td>Sequesters carbon</td>
</tr>
<tr>
<td>Adds to urban heat island effect</td>
<td>Cooling through evapotranspiration</td>
</tr>
<tr>
<td>Stormwater exported – downstream impacts</td>
<td>Stormwater retained, stream flows stabilized</td>
</tr>
<tr>
<td>Groundwater levels reduced</td>
<td>Groundwater levels maintained</td>
</tr>
<tr>
<td>Encourages automobile use</td>
<td>Promotes walking/biking</td>
</tr>
<tr>
<td>Mono-functional</td>
<td>Multi-functional</td>
</tr>
<tr>
<td>Centralized, vulnerable to failure</td>
<td>Decentralized, “fail-safe”</td>
</tr>
</tbody>
</table>

In summary, GI is not only able to increase the site’s capability of infiltrating stormwater, but also to improve the site resilience of recovering from disaster. The advantages of regenerating urban villages with GI are elaborated in the following aspects:

1. GI is more sustainable, and can often be installed and maintained on a lower budget;
2. GI not only can help support infrastructural functions but also support human activities in urban villages;
3. GI can help improve the living environment and life quality in urban villages;
4. Higher green space ratio helps raise the urban village's reputation;
5. GI can help mitigate urban flooding in Beijing by increasing infiltration area and reducing the peak flow;
6. The new green technology can attract investments and raise property value of urban villages;
7. GI can help improve people’s interaction and create the sense of community in urban villages.
To apply this idea in practice, the project selects Dayouzhuang and Saoziying, two adjacent urban villages, as the project sites in Beijing. The details of site selection and site conditions will be illustrated in the following chapters.

1.2 Definitions

Three key concepts in this project need to be clarified, "urban informal settlement", "urban village", and "green infrastructure".

1.2.1 Urban Informal Settlements

"Urban informal settlement" in this project generally refers to the following type of human settlements. According to the State of World’s Population 2007, terms such as "slum", "shantytown", "informal settlement", "squatter housing" and "low-income community" are often used interchangeably (United Nations Fund for Population Activities, 2007). All these terms refer to the settlements for the urban poor and migrants. The image of these settlements usually relates to disastrous ecological conditions, high building density, inadequate water and waste processing infrastructure, and high crime rate (David, 2006; United Nations Habitat, 2010). This project unifies these terms into “urban informal settlements”, with less negative and classist connotation. Moreover, in most of the literature, the informal settlements only refer to the settlements initiated by land invasion or encroachment. This project extends the definition of “urban informal settlements” to the type that are mostly built or are greatly altered by the residents, and therefore the municipal infrastructure does not sufficiently support the current usage.

1.2.2 Urban Villages

"Urban village", translated from the Chinese "cheng zhong cun", literally are "villages in the city", as well as "villages amid the city," "villages encircled by the city," and "city villages" (Zheng, Siqi, etc., 2009). It is a specific form of urban informal settlement in China. An urban
village is the area that has been geographically "surrounded or otherwise encroached upon by other more contemporary building types that meet modern building standards" (Zheng, Siqi, etc., 2009). They are different from the huge clusters of informal housing in Brazil or India. Chinese-style informal settlements are more scattered within the urban-suburban transit area (David, 2006; Zheng, Siqi etc., 2009).

Urban villages are the “built rural villages” that are left intact in the urbanization process (Gao, Dong, etc., 2006; Wang, Wang, 2009; Zheng, Siqi, etc., 2009). They used to be "formal settlements", but now the uncontrolled and unauthorized add-on buildings mark them as "informal settlements". Moreover, the residents in urban villages mostly do not have a local residential permit "Hukou". According to China National Committee for Terms in Sciences and Technologies, urban villages provide low-income settlements "for the rural migrants who arrive in the city for the first or second time", representing the migrant culture (2000). Transformed from formal rural settlements and composed primarily of new rural migrants are the two most remarkable characteristics of the Chinese urban villages.

In terms of living condition, they share the following common characteristics with other types of urban informal settlements. Land use is primarily residential, sometimes mixed residential with commercial (Gao, Dong, etc., 2006; Wang, Wang, 2009; Zheng, Siqi, etc., 2009). The distance between buildings is very narrow, to a degree that people in two buildings can kiss from their windows (Wang, Wang, 2009). The authorized buildings do not have adequate sewerage, sanitary facilities and waste disposal. The sanitary facilities are usually shared with others (Gao, Dong, etc., 2006; Wang, Wang, 2009). The waste disposal is close to living places (Wang, Wang, 2009). In some cases, sewerage from daily life and restaurant is discharged to the street directly (Wang, Wang, 2009). At the same time, several residents are squeezed into one small room (Wang, Wang, 2009; Zheng, Siqi, etc., 2009). The water supply has problems meeting the usage of excessive residents in the peak hours (Zheng, Siqi, etc., 2009).
However, as former traditional villages, urban villages have access to electricity, internet, cable and other facilities (Wang, Wang, 2009). Even though most of the add-on buildings are unauthorized, the construction materials are substantial concrete and bricks. Moreover, urban villages are well integrated into the regional transport network. They are highly urbanized, but incompletely so.

1.2.3 Green Infrastructure

“Green infrastructure” is a developing concept that is becoming more and more popular in urban design. Mark Benedict defines green infrastructure as “an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations” (Benedict, 2006). Jack Ahern further defines it as “an integrated network or system of built and protected urban ecosystems that provide multiple, complementary both ecosystem and landscape functions in support of urban sustainability” (Ahern, 2007). Elizabeth Mossop also states that green infrastructure “explores the relationship between natural system and the public infrastructure” in urban environments (Mossop, 2006).

These definitions indicate a process view of GI adapted from natural environment to urban environment. In Benedict's definition, green infrastructure includes "waterways, wetlands, woodlands, wildlife habitats, and other natural areas; greenways, parks and other conservation lands; working farms, ranches and forests; and wilderness and other open spaces that support native species, maintain natural ecological processes, sustain air and water resource and contribute to the health and quality of life” (Benedict, 2006). Whereas Benedict emphasizes on protecting existing resources before urbanization occurs, and outside of cities, Ahern and Mossop concentrate on restoring the ecosystem in the urban environment. Particularly, Ahern claims that the urban hydrological and drainage system principally frames the design structure of the green
infrastructure (Ahern, 2007). And Mossop considers the transportation infrastructure as the large potential to support ecological functions in the city (Mossop, 2006).

In this project, GI refers to a natural network integrated with built infrastructure that focuses on stormwater management. It includes types of GI installations that combine with roads, sewerage, and drainage system to increase the stormwater filtration, infiltration and drainage. It has multiple scale implementations from site scales to regional scales. It has multiple functions, including urban climate remediation, air quality improvement, urban hydrology restoration, biodiversity reinforcement and social activity improvement.

Particularly, to use GI to manage stormwater and improve urban hydrology is to 1) create a GI system to treat stormwater, from rooftops to streets to natural water bodies; 2) supplement the conventional infrastructure, controlling the quality and the volume of stormwater on-site as much as possible. This concept could be interpreted by the diagram below.

![Figure 1-1 Stormwater Quality and Quantity Management Diagram](image)
1.3 Research Questions

This project attempts to address the following questions:

1. What is the role of urban villages in China? What are the background and driving factors of their developments? Why it is significant to regenerate urban villages with GI?
2. How to create a GI plan to improve the stormwater management and to solve the inland flooding problem in urban villages?
3. What are the site conditions at the selected urban villages in Beijing? How do the conditions affect the GI toolbox selection?
4. How is a green infrastructure plan configured if accepting most of the existing buildings? And how is it configured if removing a certain percentage of buildings, adding new, taller buildings to save more open space?
5. Can green infrastructures designed primarily for stormwater management enhance the quality of life and provide other ecosystem services and landscape functions?

1.4 Goals and Objectives

The goal of the project is to test whether the GI alternatives would improve the stormwater management and to solve the inland flooding problem in urban villages in Beijing. The goal listed above will be accomplished by means of the following objectives:

1. Understand the advantages and problems of the urban villages;
2. Identify the similarities and differences of the urban informal settlement regeneration and redevelopment between cities in other countries and Beijing, China;
3. Find suitable project site(s) and understand the opportunities and challenges of the site(s) for applying GI;
4. Create a GI toolbox based on the project site(s) analysis;
5. Create GI alternatives for the site(s), representing the development from present, the recent future to the long-term vision;

6. Evaluate the GI alternatives in terms of improving site ability of stormwater management, as well as other environmental and social benefits.

1.5 Limitations and Delimitations

1.5.1 Limitations

Because of limited access to detailed geographic data, the project is conceptual to a certain degree. Firstly, the official information that the project collected for the site analysis does not include the municipal utilities for stormwater drainage. The existing drainage system is estimated from on-site observations. The site topography is not completed. The water flow direction is also estimated from the site spot elevations. However, this project takes a "learning by doing" (Ahern, 2007) approach working with assumptions and exploring the GI plan feasible in the urban villages.

1.5.2 Delimitations

This project has several delimitations. Firstly, the project focuses the urban villages that are located in Beijing. The main problem threatened Beijing’ urban villages is inland flooding. If the urban villages were in other cities, for example, Guangzhou, Shanghai, Chengdu, Chongqing etc. the main problem would not be inland flooding.

Besides, Beijing, where the site is located, is the city where I have lived for five years. I lived next to an urban village for my last year there. That urban village has been razed in 2010 and is still waiting for new developments. It was a lively neighborhood with small shops, street vendors, and the diversity of people. As a student, I appreciated its cheap but convenient daily supplies. As a landscape architect, I appreciate the energetic living atmosphere. I attempt to find a better future
for urban villages before they are torn down. This project is for both urban villages and the people like me who have lived or are living there.

1.6 Project Organization

In conclusion, an urban village is a specific type of urban informal settlement in China. It has severe environmental problems, but while the ongoing plan solves their problems it also neglects their contributions. The project takes two urban villages in Beijing as an example, focuses on the recent inland flooding issue, and proposes to use GI to improve the sites’ capability of infiltrating stormwater. Through the examples, the project attempts to explore the social, cultural and other benefits that GI could bring to the community.

This main body of the master’s project contains seven chapters in total. This first chapter is the introduction of project in terms of purpose, goals and objectives, research questions, and the scope of research. The second chapter is a literature review on urban informal settlements and urban villages. The third chapter describes the methodology used in the project. The fourth chapter presents the precedent projects of informal settlement regeneration, learned from the cities with successful experiences. The fifth chapter is the project site analysis. The sixth chapter is the project proposal. The seventh chapter identifies conclusions of this project and recommendations for future research.

To understand the problems involved in ongoing regenerations, the next chapter will further introduce the social, economic, and political background of urban informal settlements and urban villages in China.
2. Literature Review: Urban Informal Settlements and Urban villages

2.1 Global Background

Slum formation has increasingly become a common part of urbanization in the developing world. In 2003, UN-Habitat issued its annual report with the title of "the Challenge of Slums". For the first time, "urban informal settlements" come onto the stage of world history as a major international policy issue. The report states that now almost one billion people live in informal settlements, and the number is projected to double by 2030 (United Nations Habitat, 2003). There are approximately more than 200,000 slums on earth (Davis, 2006). The range of population in a single settlement is “from a few hundred to more than a million people” (Davis, 2006).

Urban slum population is growing rapidly as cities grow. "Slums in Southern Asia, Western Asia and Sub-Saharan Africa are growing as fast as the urban population in general" (United Nations Habitat, 2006). In Eastern Asia and Latin America, although slum growth rates are significantly lower than urban growth rates, they are also relatively high in both regions (United Nations Habitat, 2006).

Notably, although urban informal settlements are more critical during ongoing urbanization in developing countries, they do not disappear after developed countries have finished urbanization. Both developed and developing countries are facing many of the same serious issues. The issues related to urban informal settlements include poor living environment as well as socioeconomic poverty, poor primary education, gender inequity, and public health limitations (United Nations Habitat, 2006).

China is facing the largest problem of slums. The first list selects cities in the most famous developing countries with slum issues. From the list we can see those cities are marked as
megacities by the over 10 million resident population. Two of them are from China. The second list represents the slum population in the countries from where the cities are. In this list, China has 32.8% slum population, but because its large total population, the population in slums reaches to the first rank in the list in terms of absolute numbers.

<table>
<thead>
<tr>
<th></th>
<th>Total city population (thousands)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mumbai, India</td>
<td>20,072</td>
</tr>
<tr>
<td>Sao Paulo, Brazil</td>
<td>19,582</td>
</tr>
<tr>
<td>Mexico City, Mexico</td>
<td>19,485</td>
</tr>
<tr>
<td>Shanghai, China</td>
<td>15,789</td>
</tr>
<tr>
<td>Dhaka, Bangladesh</td>
<td>14,796</td>
</tr>
<tr>
<td>Beijing, China</td>
<td>11,741</td>
</tr>
<tr>
<td>Lagos, Nigeria</td>
<td>10,572</td>
</tr>
</tbody>
</table>

*Table 2-1 Total Population of Selected Megacities in 2010 (United Nation Habitat, 2008)*

<table>
<thead>
<tr>
<th></th>
<th>Population in urban (thousands)</th>
<th>Population in slums (thousands)</th>
<th>Population in slums (% of urban population)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bangladesh</td>
<td>39,350.7</td>
<td>25,184</td>
<td>70.8%</td>
</tr>
<tr>
<td>Brazil</td>
<td>157,368.9</td>
<td>45,509</td>
<td>28.9%</td>
</tr>
<tr>
<td>China</td>
<td>530,659.3</td>
<td>174,745</td>
<td>32.8%</td>
</tr>
<tr>
<td>India</td>
<td>325,563</td>
<td>110,225</td>
<td>34.8%</td>
</tr>
<tr>
<td>Mexico</td>
<td>325,563</td>
<td>11,686</td>
<td>14.4%</td>
</tr>
<tr>
<td>Nigeria</td>
<td>65,270.1</td>
<td>41,664</td>
<td>65.8%</td>
</tr>
</tbody>
</table>

*Table 2-2 Informal Settlement Population and Urban Population of Selected Countries in 2010 (UN-HABITAT Urban Indicator Database, 2013)*
2.2 History and Driving Factors of Urban Informal Settlements

Worldwide, the growth of urban informal settlements has generally been initiated by the massive rural-urban migration within predominantly rural countries as they transform into urban-industrial economies. People from rural areas have flowed into cities, responding to urban job opportunities and rural economic displacement. This phenomenon first appeared in the early 19th century industrializing London (United Nation Habitat, 2006). The migrants are attracted by more job opportunities, more civil rights and freedom, and better life for their families (United Nation Habitat, 2006). Where the migrants settled and lived became the early form of urban informal settlements.

The urban informal settlements are typically considered unfavorable communities in cities. Along with the lack of municipal planning and infrastructure, this form of development resulted in the chaotic spatial organization and poor environment in the settlements. The residents of informal settlements are mostly from the working class, which are considered poor and uneducated. These global situations are where the "shanty town", "slum", "favela" settlements come from. Urban informal settlements are largely denied and excluded by the city, and are often removed.

In the past decades, however, City governments have taken great efforts to upgrade informal settlements, but the results have turned out to be disappointing. For example, it has been tried in many cities to relocate the original slum residents in the new satellite cities, such as Cairo, Mumbai, Delhi, and Mexico City (Davis, 2006). In most of the cases, the new suburban cities are already full of people from adjacent rural areas or middle class commuters (Davis, 2006). When the previous informal settlements have been removed, again the urban poor have to struggle to find another neighborhood that could fit their requirement of cheap price and close distance to jobs. Therefore, the urban informal settlements constantly exist, responding to the need.
1. Initiate | Migrants came from villages to cities
2. Establish | Informal settlements formed
3. Deny | Informal settlements eliminated and satellite cities built
4. Continue | Satellite cities failed and another urban villages emerged

Table 2.3 Historical Development of Urban Informal Settlements in Global Context

According to the historical stages of urban informal settlements, the causes and driving factors of urban informal settlements could be classified into economic, social and political aspects as follows.

<table>
<thead>
<tr>
<th>Economic</th>
<th>It is driven by global industrial and economic revolution.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rural people respond to the requirement of cheap laborers in the urbanization.</td>
</tr>
<tr>
<td>Social</td>
<td>Rural migrants are in a low social status in cities.</td>
</tr>
<tr>
<td></td>
<td>Informal settlements are rejected by the city.</td>
</tr>
<tr>
<td>Political</td>
<td>Landownership regulations are weak in controlling people who build and rebuild spontaneously.</td>
</tr>
<tr>
<td></td>
<td>Current policy is not responding to the massive migration.</td>
</tr>
</tbody>
</table>

Table 2.4 Causes and Driving Factors of Urban Informal Settlements

Nevertheless, due to the particular situation in economics, politics, culture, and urban structure, the informal settlements in different countries have their own characteristics. In the next section, the chapter will continue to explain specifically the history and the driving factors that shaped the Chinese urban villages.
2.3 China Context

2.3.1 Massive Population Migration after Market Reform

The massive population migration in China was initiated by the Market Reform in 1970s. In the Market Reform, the policy of economic liberalization was adopted, transforming a centralized planned economy to a market economy (United Nation Habitat, 2008). Consequently, many cities took advantage of their locations and started to develop private industries, especially in the harbor and coastal areas.

In this reform, the massive population migration brought people from less developed cities/towns/villages to urbanizing cities (e.g. coastline cities, industrial cities, and the capital cities of the province). The Pearl River Delta (PRD) became one of the fastest growing regions and a major manufacturing center in the country and even in the world. For example, the population of Shenzhen increased from 600,000 to 3,000,000 in 15 years after Market Reform,
and then reached to 10,000,000 less than 10 years after that. Later, the big cities responded to this as well. Now along the Pearl River (Hong Kong-Shenzhen-Guangzhou), the Yangzi River (Shanghai) deltas, and the Beijing-Tianjin corridor, there are cities on their way to developing urban-industrial megacities comparable to Tokyo-Osaka, the lower Rhine, or New York-Philadelphia (Davis, 2006).

2.3.2 Two Types of Residential Permit

However, the massive population migration is restricted by the outdated administration policy—i.e., the residential permit system.

China has two different types of residential permit (Hukou in Chinese), which classifies citizens in China as either the agricultural (rural) population or the non-agricultural (urban) population (Zheng, Siqi etc., 2009). This system was established in 1950s, after the founding of the People's Republic of China.

It was designed to administer the population migration in China and to guarantee the respective welfare and benefits according to rural population or urban population. Especially in terms of landownership, the urban resident permit holders are restricted from developing their private land, but the rural resident permit holder can develop land.

Moreover, the welfare and benefits guaranteed by the residential permits are only effective in the local place specified on the residential permits. People with a residential permit from a different place are not eligible to enjoy the local welfare and benefits in a new place – causing significant social problems including income, access to health care, and access to education.

This policy caused two major conflicts in the process of urbanization, which shaped urban villages, the Chinese-style of urban informal settlements. The following sections will illustrate how these two conflicts happened in the process of urban village development.
2.3.3 Conflict of Urban Development and Outdated Land Policies

Urban development—Farmland Acquisition—Early urban villages

As the cities continue developing, more land is needed beyond the existing city borders. In China, there was a clear difference between the city with constructed land and the countryside with farmland. In this case, city governments have to take "a piecemeal approach" to acquire the farmland from local farmers. From 1999 to 2008, the increased area of urban construction land has reached to 18,633 square kilometers. Of this total, 13,925 square kilometers were from expropriation of farmers' land, accounting for 74.74% of the total increased land.

However, many of the villages have been left intact. An important reason was the Residential Permit System. Removing the village would cause the relocation of the villagers and the change of their residential status (Wang, Wang and Wu, 2009). But in the early years of urbanization, governments did not have enough funding and labor to manage this change, and so they avoided the village relocation and redevelopment. The villagers lost their farmland, but kept the rural residential permit and the housing. After new developments were built on the acquired farmland, the traditional villages were encompassed and became the early urban villages.

2.3.4 Conflict of Mass Population Migration and Inadequate Housing

Massive population migration—Inadequate affordable housing—Urban village accommodations

Meanwhile, when the massive population migration has come to cities attracted by the economic development and employment opportunities, housing becomes a problem for them. Because of the Residential Permit System, they are not qualified for affordable housing provided by the city government. Moreover, limited by their ability and background, migrants are often earning less than the city average. They generally cannot afford market-rate housing either.
Responding to this demand, the urban villagers found out this opportunity and turned their way of living to land and property-related businesses. Because of the Residential Permit System, the rural residential permit holders have the special private ownership of land, so they are able to make additions and alternatives to their own houses to accommodate more tenants. Here is an extreme example from Shenzhen: the FAR in a mature urban village could reach to 3.0 in a very high density, as compared to an average FAR of 1.0-1.5 (Wang, Wang and Wu, 2009).

2.3.5 Advantages and Problems of Urban Villages

Advantages

Urban villages have provided the ideal housing to migrants. Firstly, they are usually in walking or biking distance to work places. Secondly, the rent fees and the living expenses are much lower than the average costs in the city. Moreover, urban villages are the localized representation of the current migrant culture.

Problems

First, urban villages are threatened by environmental impacts and disasters, for example inland flooding. The high impervious paving rate and the inadequate drainage system result in a readily flooding condition during monsoon season, which will be elaborated in the next section. Second, the living conditions are poor. The unauthorized buildings occur on an unprecedented scale, far beyond the governments' control. The urban villages are not adequately serviced by existing infrastructure, such as water supply, sewage, drainage, waste disposal, etc. Moreover, without adequate municipal utilities, the high-density living condition in urban village is hardly viable or endurable. Third, the poor built environment causes negative impacts on natural environment. For example, the untreated wastewater usually discharges into natural water bodies directly. In
addition, all of these problems result in the low public reputation of urban villages, causing the problem of social justice and equity.

2.3.6 Urban Inland Flooding in Beijing

As affected by global climate change, the precipitation become more concentrated and frequent in Beijing during the summer season. The urbanized environment cannot support enough infiltration in the unit hour, and therefore the inland flooding has happened more frequently and severely. Especially in the urban villages, the highly urbanized environment and the inadequate municipal utilities have weakened their capability of absorbing stormwater. Most of the urban villages are suffering from inland flooding during the big rainstorms in the summer season.

2.4 Conclusion

In summary, the strategy to promote urban village regeneration should keep the advantages and fix the problems. From the history of urban informal settlements, we can learn that they are still playing a key role in accommodating the migrants in urban areas. In the Chinese context, urban villages responded to the problems caused by Residential Permit System in the urbanization process. Urban villages provide affordable housing to migrants who are not covered by the local benefits and welfare programs. Although they are suffering from the poor living environment and the inland flooding issue, these villages are an important part of the developing cities. The next chapter will further explain the methods used in this project, focusing on solving the inland flooding in Beijing urban villages by GI.
3. Methodology

In order to answer the research questions and accomplish the goals and objectives, this project will take the following steps in terms of research strategy and process.

1. Review the literature on urban informal settlements and urban villages to understand their roles in urban development, particularly identifying the environmental problems of urban villages in Chinese context;

2. Conduct precedent studies on the successful urban informal settlement upgrading projects in other countries, and compare their environmental problems and landscape strategies with Beijing’s;

3. Select typical developing urban village(s) suffering from the target environmental problem—inland flooding, as the project site(s);

4. Conduct the site visit and analysis, analyzing the existing environmental conditions to identify the challenges and opportunities of applying GI, such as stormwater flow, drainage, impervious pavement coverage, vegetation coverage, land use, building conditions, and street conditions;

5. Create a GI toolbox based on the analysis, categorizing the GI tools by the characteristics of stormwater quantity/quality control, ecosystem services, and installation requirements;

6. Create a masterplan of stormwater management system based on the analysis;

7. Create GI alternatives with the GI toolbox: specifically a lower-level intervention plan and higher-level intervention plan;

8. Estimate the relative positive impact of GI alternatives by calculating and comparing the metrics of GI used in the alternatives, including but not limited to the change in pervious pavement percentage, canopy cover percentage, and total GI area percentage.
Based on the understanding of the methodology, the following chapter will learn from the precedent studies of urban informal settlements development, conditions and upgrading in Mumbai and Sao Paulo, and then compare those ‘best practices’ with the situations in Beijing’s urban villages.
4. Precedent Studies

In order to evaluate the problems and solutions of environmental quality for urban villages in Beijing, this chapter will introduce case studies of the urban informal settlements in Mumbai, Sao Paulo, and Beijing in terms of geography, climate, urban informal settlement distribution, conditions, problems and landscape interventions. For each city, the stages of urban informal settlement development are organized in chronological order. The end of the chapter will create a table to compare those characteristics of urban informal settlements in the three cities.

4.1 Mumbai, India

Geography and Climate

Mumbai is located in a complicated estuary of river flowing into the Arabian Sea, with a rich coastal habitat. Most of the city is just above the sea level. The average elevation of Mumbai is about 14 m. Mumbai has a humid tropical climate. The annual temperature remains fairly even throughout the year, about 27 ºC. The annual precipitation concentrates in summer. About 95% of the 2,146 mm total annual precipitation happens in the summer monsoon season.

The city is very vulnerable to water and easily flooded. On July 26th 2005, Mumbai suffered from an extreme rainstorm, with daily rainfall of 944mm, the highest recorded in a single day in the city’s history. The flooding caused huge damage and loss of people’s lives, properties, and possession.

Urban Informal Settlements

The total area of Mumbai (or Greater Mumbai) is 604 km², and the Island City (City District) accounts for 68 km² of its total. By 2001, 1,959 slum settlements have been identified with a total
population of 6.25 million, which forms 54% of the total population of the city. The city’s population was projected to reach to 20.5 million by 2012, and the population in urban informal settlements still occupies a considerable proportion (United Nations Habitat, 2008).

The informal settlements are commonly called slums in India, a word that describes their temporary building materials in an unstable condition. The urban informal settlements are built spontaneously by the residents, and therefore typically do not have the water supply, sewage, and solid waste facilities connected to the municipal system. The living conditions in urban informal settlements are hardly endurable and the environment surrounding is highly contaminated by sewage and other wastes (Fig. 4-1).

The map below shows the urban informal settlement distribution in 2010 from the Mumbai Planning Institute (Fig. 4-3). The map indicates that the urban informal settlements in Mumbai are mostly spread in the suburban area, due to the limited land of the City District. Moreover, in the City District, the distribution of urban informal settlements indicates a close relationship to the floodplain, which is the most available land for slum builders close to the urban center to settle. The next section will further discuss the locations of urban informal settlement and their impacts on the environment via specific case examples.
cases of urban informal settlements

Four urban informal settlements have been selected and analyzed, to study their environmental impacts on Mumbai’s environment. Their respective names are Dharavi, Worli, Antop Hill, Colaba (Fig.4-4, Fig. 4-5, Table 4-1).
Table 4-1 Comparison of Land Area and Site Features of Dharavi, Worli, Antop Hill, and Colaba (Source from Google Map)

<table>
<thead>
<tr>
<th>Informal Settlements</th>
<th>Type</th>
<th>Land Area (ha)</th>
<th>Site Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dharavi</td>
<td>Spontaneous Settlements</td>
<td>220</td>
<td>Floodplain on the south bank of the Mithi Creek, next to mangrove forest</td>
</tr>
<tr>
<td>Worli</td>
<td>Spontaneous Settlements</td>
<td>30</td>
<td>Floodplain pointed in to the sea with the historical fort</td>
</tr>
<tr>
<td>Antop Hill</td>
<td>Spontaneous Settlements</td>
<td>100</td>
<td>Landfill site near to the major transport and job market</td>
</tr>
<tr>
<td>Colaba</td>
<td>Spontaneous Settlements</td>
<td>30</td>
<td>Floodplain right on the seashore, invaded into mangrove forest</td>
</tr>
</tbody>
</table>

Those urban informal settlements occupy a large land area with a FAR as low as 1.0. The building density is extremely high and the height is low, generally one-story. That is restricted by the city regulation that the average FAR in Island City should not exceed 1.33. The regulation is considered as one of the important reason for the sprawl of urban informal settlements in the South Mumbai.

From the aerial photo of each slum, we can see more clearly the their close relationship to water. Some of them are located in the environment preservation area. For example, the Mithi Creek, on the south bank of which Dharavi is located, is the area where the Mithi River connects to the Arabian Sea. However, the creek becomes the major waste disposal site of Dharavi, and is
therefore heavily polluted. Moreover, in Colaba, the site was growing mangrove forest, but the building of urban informal settlements destroyed the habitat in the mangrove forest.

In summary, the sprawl of urban informal settlements negatively affects the environment in Mumbai. The urban informal settlements destroy the natural buffer of the costal land, and weaken the protection of South Mumbai from flooding.

**Government Strategies and Landscape Interventions**

The government regeneration of urban informal settlements in Mumbai has attempted to add the fundamental infrastructure and improve the existing living environment. Also, the government considers the urban informal settlements as an important opportunity and challenge to recover the city’s ecosystem. By improving the sanitary and drainage system in the urban informal settlements, the city's water system can be cleaned and the wetland habitat can be recovered.

The development of this idea is found in *Soak* by Anuradha Mathur and Dilip da Cunha (2009). In terms of the flooding issue in the South Mumbai, the book argues that the strategy should adapt to the daily possibility of flooding, and creatively propose the soft infrastructure—recover the destroyed coastal habitat and increase the land’s capability of "soaking water". The redevelopment of urban informal settlements also is included in the proposal. For example, in Worli Fort, as a part of waterfront habitat recovering, the transformed barges provide sanitary facilities to the urban informal settlements, and moreover cultivate foods, treat wastes, and produce energy for the whole site.
Moreover, an exemplary project of this idea was built in Indore, India. Slum Networking, the title of the project, improved the sewerage and storm drainage, the planting of gardens, and the surfacing of roads, and used this as a starting point of upgrading the major sewerage artery and drainage system along the city’s river, therefore to change the whole city environment.
4.2 Sao Paulo, Brazil

Geography and Climate

Sao Paulo is located in a plateau embraced by the “Serra do Mar”, which means the “Sea Ridge”—a system of mountain ranges and escarpments near the Atlantic Ocean in Southeastern Brazil. The region is very hilly with an average elevation of 800m above sea level. Sao Paulo has a monsoon-influenced humid subtropical climate. The daily mean temperature in summer is about 21°C, and in winter is about 17°C. The annual precipitation is around 1,460mm, about 50% of which concentrates in summer. The monthly average precipitation in summer is about 220mm.

As the humid subtropical climate, the precipitation in Sao Paulo is not as concentrated as that in Mumbai. However, the rainy weather in summer increases the risk of landslides on the steep hillsides. This results in the settlements near hillsides facing a dangerous condition. The next section will introduce the settlements that sit on the hillside—favelas, the urban informal settlements in Sao Paulo.

Urban Informal Settlements

The Metropolitan Area of Sao Paulo is 7,943km², 1,523km² of which is the City of Sao Paulo, a much larger land area than that of Mumbai. The population exploded in the extensive urban area
generally, as well as the population in the informal settlements specifically. By 2011, the population in the metropolitan area has reached 19.87 million, and the population in informal settlements increased to 4 million (Werthmann, 2011). Heliopolis, Paraisopolis, and Sao Francisco are the top three largest favelas in the city, housing approximately 160 thousand inhabitants.

The urban informal settlements in Brazil are commonly called favelas, the invasive land developments built by residents spontaneously. The residents have the ownership of the land and the housing. Besides poor housing and infrastructure condition, the considerable number of favela residents is threatened by natural disaster as well. This is because the occupying settlers have little choice but build their housing on the leftover land of the city developments, hillside or floodplain, which is usually close to the important environmental preservation area (Fig. 4-9). The invasive developments destroy the land cover on the hillside and contaminate the water bodies. They suffer from landslides, imperiled drainage channel, and polluted drinking water in turn.

The map below shows the distribution of informal settlements in the City of Sao Paulo (Fig. 4-11) (Werthmann, 2011). The map represents a more extensive sprawl of urban informal settlement
compared with that in Mumbai. Also, from the map we can tell the close geographic relationship between favelas and environmental preservation areas. For example, around Billings and Guarapiranga Reservoir, there is an extensive area encroached by favelas. The next section will introduce specific cases to further discuss the relationship between favelas and environmental quality.

Cases of Urban Informal Settlements

Five favelas—Bamburral, Paraisopolis, Cantinho de Ceu, Heliopolis, and Sao Francisco—are selected as examples to understand the environmental impacts of urban informal settlements in Sao Paulo (Fig. 4-12, Fig. 4-13, Table 4-2). All these five favelas have already begun the upgrading process by the city government, although they have not finished yet, but the next section will illustrate their problems before upgrading.
Figure 4-12 Locations of Cantinho de Ceu, Heliopolis, and Paraisopolis (Source from Google Map)

Figure 4-13 Aerial Maps of Bamburral, Paraisopolis, Cantinho de Ceu, Heliopolis, and Sao Francisco (Source from Google Map)

<table>
<thead>
<tr>
<th>Informal Settlements</th>
<th>Type</th>
<th>Land Area (ha)</th>
<th>Site Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bamburral</td>
<td>Spontaneous settlements</td>
<td>50</td>
<td>In a permanent preservation area; steep hillside, contaminated water channel</td>
</tr>
<tr>
<td>Paraisopolis</td>
<td>Spontaneous settlements</td>
<td>120</td>
<td>Near urban area, job market and premium transport facilities, hilly land base, contaminated water channel</td>
</tr>
<tr>
<td>Cantinho do Ceu</td>
<td>Spontaneous settlements</td>
<td>150</td>
<td>On a floodplain, next to the Billings Reservoir</td>
</tr>
<tr>
<td>Heliopolis</td>
<td>Spontaneous settlements</td>
<td>100</td>
<td>On a hilly land base, contaminated water channel</td>
</tr>
<tr>
<td>Sao Francisco</td>
<td>Spontaneous settlements</td>
<td>180</td>
<td>On a hillside, include a landfill site of 37 ha in area</td>
</tr>
</tbody>
</table>

Table 4-2 Comparison of Land Area and Site Features of Bamburral, Paraisopolis, Cantinho de Ceu, Heliopolis, and São Francisco (Source from Google Map)
These five urban informal settlements represent the sprawl of low FAR settlements. The building height is as low as that in Mumbai, about 1-2 stories high. But different from Mumbai, Sao Paulo’s development is not limited by water. The five urban informal settlements spread extensively in the hilly landform or the floodplain, occupying a large land area. The sprawl of urban informal settlements is even more severe than that in Mumbai.

Moreover, the selected cases represent or represented the conflict between the urban informal settlements and the natural environment. Steep hillsides could become unstable during the rainstorm. For example, Bamburral is located in a permanent preservation area. There is an area of 4ha located in a steep hillside and lack of land cover, which is considered at the high risk of hazard. In the rainstorm, stormwater flows could wash the loose earth and debris and therefore destroy the community. The impact of the urban informal settlements on water bodies is also notable. Among five cases, four of them have a significant contamination of water. The river channels in the community are usually obstructed by debris and waste. Especially, the Cantinho do Ceu is on the bank of the second largest water body in the city—Billings Reservoir, but the sewerage and polluted stormwater from the favela discharges to the reservoir without proper treatment, which even threatens the city’s water supply.

**Government Strategies and Landscape Interventions**

The city government acknowledges the contribution of urban informal settlements. To mitigate their negative impact on environment, the city government has already proposed and implemented innovative plans to the exemplary favelas. With the means of green infrastructure, the new plans transform the urban informal settlements into more sustainable communities, in harmony with the environment. The details of upgrading plans include eliminating hazard areas, cleaning the water channel, building new housing, implementing sewerage, drainage and water system, paving roads, and creating public spaces. The upgraded favelas remain the affordable housing to the original residents, with higher FAR to accommodate more people.
An exemplary project is the Paraisopolis upgrading. The project receives BRL 500 million from the municipal, state and federal governments as the start of the upgrading project. The project creates approximately two thousand housing units and commercial units (Sao Paulo Calling, 2012). Moreover, the project creates a green infrastructure network in the community, connecting small pocket parks (Fig. 4-14, Fig. 4-15, Fig. 4-16). A bike path loop also is created in the community and connected to the city bike path system.

Figure 4-14 Green Infrastructure Network in Paraisopolis (Source from Sao Paulo Calling, 2012)

Figure 4-15 Plan of A Pocket Park in Paraisopolis (Source from Sao Paulo Calling, 2012)
Besides the city government, the international design institute involved in the favela upgrading project also proposes to use green infrastructure for mitigating the conflict between urban informal settlements and environment. The Harvard Design School conducted a study on the Cantinho do Ceu, and created 13 tactics for reducing the pollution from the informal settlement as well as increasing the community reputation and social connection. The study argues that the large-scale centralized engineering project is not effective in the environment preservation area. The decentralized water management will be the alternative. For instance, the tactic "Increasing Biomass" improves the streets with green infrastructure (Fig. 4-17, Fig. 4-18). The project is on the conceptual level, but the idea is innovative and practical, using green infrastructure to limit the negative impact of informal settlement on water bodies. By increasing the tree canopy, the quality and quantity of stormwater can be controlled throughout the favela from the beginning, decreasing the levels of flooding, erosion and water pollution.
In summary, the favela upgrading in Sao Paulo has been going on successfully. It collects wisdom from both local and international sources, as well as government and academia. The various ideas present a great opportunity for green infrastructure in urban informal settlement regeneration. Especially the idea of decentralized stormwater management has the potential to effectively control the water pollution and reduce the environmental impacts from urban informal settlements.
4.3 Beijing, China

Geography and Climate

The Municipality of Beijing is located at the northwest tip of an important agricultural area in the country— the North China Plain. Different from Mumbai and Sao Paulo, Beijing is an inland city with a flat landscape. The average elevation of the city is 46m. Beijing has a humid continental climate, marked with a hot humid summer and cold dry winter. In Beijing, the monthly daily average temperature in January is −3.7 °C, while in July it is 26.2°C (2000). The average annual precipitation is 570mm, 423mm of which concentrates summer monsoon season (2000).

Because of the excessive groundwater usage on agriculture and the increasing impervious pavements in urban developments, the city has suffered from groundwater decline and water shortage. Moreover, in recent years, the heavy rains happen in the summer season, resulting in disastrous urban inland flooding. In July 21, 2010, the heaviest rainfall in 61 years fell on Beijing, bringing an average rainfall of 170 mm—the severest area even reached to 460mm, the recorded highest precipitation in the city’s history. The heavy rainfall caused a huge loss of people’s lives and property. 77 people died in the aftermath of the storms. The rainfall covered 90% of the area of the city, including the urban informal settlements.

The decreasing of surface infiltration in the highly urbanized environment is considered one of the most important reasons for the flooding. The same is true in urban informal settlements. Moreover, the inadequate drainage system exacerbates this hazardous situation. The following sections will further introduce the conditions of urban villages.
Urban Informal Settlements

The Municipality of Beijing is 16,801km², including 1,086km² of the Beijing Metropolitan Area (BMA). By 2010, the population in the Municipality of Beijing reached 22.44 million, with 13.54 million living in the BMA (National Demographic Census, 2010). In BMA, 42% of the population consists of migrants with temporary resident permit, of which a considerable part live in the urban villages.

Different from the spontaneous development in Mumbai and Sao Paulo, urban villages transform from the old rural settlements. The urban villages have the basic infrastructure in sewerage, drainage, waste disposal and sanitary facilities. Building materials are substantial, and the roads are paved (Fig. 4-21). However, the infrastructure is not able to support the increasing rural migrants. The water pressure is reported too low to provide ta water in the second story. When heavy rains happen, the drainage system also has problems to manage stormwater effectively. Moreover, because of low sense of community, the residents, who are predominantly tenants, do not become actively involved in environmental maintenance and improvement. The urban villages require strategies for improving the living environment and building the sense of community.
In Beijing, urban villages are distributed from the semi-urban area to the urban-rural transit area (Fig.4-22). Different from Mumbai and Sao Paulo, the urban villages are not threatened by geological conditions. They are developed and surrounded by highly modified urban environment. Moreover, most of the urban villages are close to municipal transportation and job markets (fig.4-23). The next section will further discuss the specific cases of urban villages to understand their living conditions and environmental impacts.
Cases of Urban Informal Settlements

Four villages, Tangjialing, Dawangjingcun, Liulangzhuang, and Saoziying are selected as study cases. Except Saoziying, the other three urban villages have already been razed and changed to new developments. Here will introduce their conditions before the removal.
Informal Settlements | Type | Land Area (ha) | Site Features (before removing)
--- | --- | --- | ---
Tang Jia Ling 唐家岭 | Old formal settlements | 70 | Near computer and engineering companies and on the subway route
Da Wang Jing Cun 大望京 | Old formal settlements | 105.6 | Near a district business center and on the highway to the airport
Liu Lang Zhuang 六郎庄 | Old formal settlements | 55 | Near a district business center and high-tech industry center, with convenient transport hub and on the subway route
Sao Zi Ying 骄子营 | Old formal settlements | 9 | Surrounded by universities and important historical landscape heritages

Table 4-3 Comparison of Land Area and Site Features of Tangjialing, Dawangjingcun, Liulangzhuang, and Saoziying (Source from Google Map)

First, different from the horizontal sprawl in Mumbai and Sao Paulo, the mode of sprawl in these four urban villages represents a vertical growth. For example, in Tangjialing, the FAR was estimated between 2.0 to 3.0 before removal. According to the news, over 10 thousand people were living in the area of 70ha and the authorized buildings had reached to five stories (2009). Similar situation is found in Liulangzhuang. The 55ha land area provided housing for 60 to 70 thousand people (2009).

80% of the residents living in the urban villages are migrant tenants. In Tangjialing, there were 50 thousand migrants with less than 3 thousand local villagers (2009). Liulangzhuang had 40 to 50 thousands tenants but only 10 thousand local villagers. There were buildings merely for renting. Those buildings were like dorms, several people living in a bedroom and sharing bathrooms and kitchens. There was hardly any open space for people to have social and recreational activities.
Those urban villages also suffer from the shortage of drainage infrastructure and high risk of flooding. The elevation of the urban villages is usually lower than that of the surrounding new developments. During heavy rainfalls, the surface overflow gathers to the urban villages. Moreover, the drainage system in the urban villages is aged. Therefore, the urban villages easily become the flooding hazard areas. According to the government documents, each year during the monsoon season, the Saoziying Residents’ Committee is busy in preparing for the possible flooding. The next section will introduce the government strategies to the problems in the urban villages.

**Government Strategies and Landscape Interventions**

To resolve the problems in the urban villages, the Beijing government generally proposes to remove the entire village and attract new developments. In 2004, the urban villages removal started surrounding the current site of the Olympic Forestry Park. A 3ha urban village was transformed to an open green space for the 2008 Olympics. In 2009, the Beijing government issued the formal removal plan of 50 major urban villages. The 50 urban villages are located in nine of the sixteen districts of Beijing Municipality, including Tangjialing, Liulangzhuang, and Dawangjingcun mentioned above. The plan has almost completed by the end of 2012. Now, the original site of Tangjialing was transformed partly to a conservation park and partly to a high-rise residential community. Dawangjingcun is planed to build the new Central Business District. The project is still under progress. Liulangzhuang has finished the removal, and waits for the development decision. Although the removal plan has succeeded, the housing for migrant tenants remains a problem.
This year, a new strategy is issued. It suggests a new developing direction of urban village regeneration (2013). The government claims that 500 billion will be invested in the 5 year regeneration of the urban villages inside the 4th Ring Road, where the urban center is. The new strategy demonstrates that the old redeveloping mode has to change. The new urban village regeneration should focus on creating secure and sustainable new urban communities from urban villages by improving the fundamental infrastructures and green spaces. It indicates an important signal for urban village regeneration.
4.4 Stages of Urban Informal Settlement Development in Each City

The following tables show the stages of urban informal settlement development in Mumbai, Sao Paulo, and Beijing. They compare the changes on infrastructures, FAR, building density and green space area through different stages in each city.

Generally, the urban informal settlements in these three cities include similar developing stages. First is the Establishment. Early urban informal settlements are formed from illegal land encroachment or residue of farmland acquirement. Second is the Maturation. Urban informal settlements continue growing to important residential areas. Third is the government and landscape intervention. Government and academia come and solve the problems in the urban informal settlements.

<table>
<thead>
<tr>
<th>Mumbai, India</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landownership</td>
<td>Illegal invaded</td>
<td>Legalized occupied</td>
<td>Legalized occupied</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>No infrastructure (original floodplain, no sewage, drainage, water supply, and sanitary)</td>
<td>Insufficient infrastructure (unpaved roads, Insufficient sewage, drainage, water supply, and sanitary)</td>
<td>Municipal Infrastructure (roads, sewage, drainage, potable water supply, sanitary, recovering natural wetlands)</td>
</tr>
<tr>
<td>FAR</td>
<td>1.0 (estimated)</td>
<td>1.0 (estimated)</td>
<td>1.0-1.5 (estimated)</td>
</tr>
<tr>
<td>Building Density</td>
<td>70%-90%</td>
<td>70%-90%</td>
<td>60%-75%</td>
</tr>
<tr>
<td>Green Space</td>
<td>No</td>
<td>No</td>
<td>District parks, pocket parks, stadiums, green streets</td>
</tr>
</tbody>
</table>

Table 4-4 Stages of Urban Informal Settlement Development in Mumbai, India
### Sao Paulo, Brazil

<table>
<thead>
<tr>
<th>Landownership</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illegal invaded</td>
<td></td>
<td>Legalized occupied</td>
<td>Legalized occupied</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>No infrastructure (original floodplain or hillside; no sewage, drainage, water supply, and sanitary)</td>
<td></td>
<td>Insufficient infrastructure (unpaved roads; Insufficient sewage, drainage, water supply, and sanitary)</td>
<td>Municipal Infrastructure (roads, sewage, drainage, potable water supply, sanitary, stabilizing the hillside, recovering the natural water bodies)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FAR</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0-1.2 (estimated)</td>
<td></td>
<td>1.0-1.2 (estimated)</td>
<td>1.0-1.5 (estimated)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Density</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%-90%</td>
<td></td>
<td>70%-90%</td>
<td>60%-75%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Green Space</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td></td>
<td>No</td>
<td>District parks, pocket parks, stadiums, green streets</td>
</tr>
</tbody>
</table>

**Table 4-5 Stages of Urban Informal Settlement Development in Sao Paulo, Brazil**

### Beijing, China

<table>
<thead>
<tr>
<th>Landownership</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Villagers owned, partly tenants occupied</td>
<td></td>
<td>Villagers owned, dominately tenants occupied</td>
<td>Varied from each new development</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Infrastructure</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural infrastructure(paved roads; sewage, drainage, water supply, and public sanitary)</td>
<td></td>
<td>Insufficient infrastructure(paved roads; insufficient water supply, under-maintained sewage, drainage, and public sanitary)</td>
<td>Varied from each new development</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FAR</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8-1.2 (estimated)</td>
<td></td>
<td>1.0-2.0 (estimated)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Building Density</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%-30%</td>
<td></td>
<td>70%-90%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Green Space</th>
<th>Stage 1 Establishment</th>
<th>Stage 2 Maturation</th>
<th>Stage 3 Government and Landscape Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmland</td>
<td></td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4-6 Stages of Urban Informal Settlement Development in Beijing, China**
4.5 Comparison of Urban Informal Settlements in Mumbai, Sao Paulo, and Beijing

Based on the studies on the urban informal settlements in Mumbai, Sao Paulo, and Beijing, this section creates a table, as a summary, comparing the characteristics illustrated above.

First, although all three cities suffer from concentrated rainfalls in the summer season, the disasters are different according to their geographical settings. Unlike overwhelming water in Mumbai, Beijing suffers from both water shortage and urban inland flooding.

Second, although all the urban informal settlements in the three cities share the characteristics of high building density, the level of the high density is different. The FAR of Mumbai is less than that of Sao Paulo. Urban villages in Beijing are similar to Sao Paulo, around 1.5-2.0. In Beijing, most of the old buildings in urban villages are one story. The self-reconstructed ones are from two to four stories.

Third, the urban informal settlements in the three cities have different degrees of municipal infrastructures. Compared with the original conditions of urban informal settlements in Mumbai and Sao Paulo, urban villages in Beijing have paved road, basic water, drainage, and sewerage system, and public sanitary.

Fourth, all the urban informal settlements have the problem of lacking green open spaces because of the high building density. However, both of the Mumbai and Sao Paulo governments use green infrastructure combined with conventional infrastructure. This strategy, without high-level intervention and massive removal, improves the capacity of municipal facilities and creates sustainable green communities, which is quite different from Beijing’s old mode of urban informal settlement redevelopment.
Finally, the strategies in Mumbai and Sao Paulo are more effective than that in Beijing. In Mumbai and Sao Paulo it was demonstrated that the landscape interventions significantly improved the living conditions of urban informal settlements; in Beijing, although the removal process is slowly continuing the new developments require time to follow up. The removal did not solve the problem of urban villages in Beijing as it was expected. Therefore, the government claims that they are planning to change the old redevelopment mode to a more green and sustainable one.

<table>
<thead>
<tr>
<th></th>
<th>Mumbai, India</th>
<th>Sao Paulo, Brazil</th>
<th>Beijing, China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>Humid tropical climate, monsoon season from May to September</td>
<td>Humid subtropical climate, monsoon season from October to March</td>
<td>Humid continental climate, monsoon season from July to August</td>
</tr>
<tr>
<td>Geography</td>
<td>Estuary: waterfront</td>
<td>Plateau: hilly landform</td>
<td>Plain: inland</td>
</tr>
<tr>
<td>Total population</td>
<td>20,500,000</td>
<td>19,867,000</td>
<td>19,612,000</td>
</tr>
<tr>
<td>Percentage of informal settlement population</td>
<td>32%</td>
<td>20%</td>
<td>36%</td>
</tr>
<tr>
<td>Informal Settlement types</td>
<td>Slums</td>
<td>Favelas</td>
<td>Urban villages</td>
</tr>
<tr>
<td>FAR</td>
<td>1.0 (estimated)</td>
<td>1.0-1.2 (estimated)</td>
<td>1.0-2.0(estimated)</td>
</tr>
<tr>
<td>Building Density</td>
<td>70%-90%</td>
<td>70%-90%</td>
<td>70%-90%</td>
</tr>
<tr>
<td>Origin</td>
<td>Spontaneous settlements</td>
<td>Spontaneous settlements</td>
<td>Former rural settlements</td>
</tr>
<tr>
<td>Dominant residents</td>
<td>Rural migrants, workers</td>
<td>Rural migrants, workers</td>
<td>Rural migrants, villagers</td>
</tr>
<tr>
<td>Tenancy</td>
<td>Owner occupied</td>
<td>Owner occupied</td>
<td>Tenant occupied</td>
</tr>
<tr>
<td>Distribution</td>
<td>Forts, Floodplains, environmental preservation areas</td>
<td>Hillsides, reservoir banks, environmental preservation areas</td>
<td>Semi-urban area, urban-rural transit area, urban environment</td>
</tr>
<tr>
<td>Major nature disasters</td>
<td>Flooding</td>
<td>Flooding, landslide</td>
<td>Urban inland flooding</td>
</tr>
<tr>
<td>Buildings</td>
<td>Mostly temporary materials: woods, plastics, fabric</td>
<td>Started with temporary materials, now mixed with permanent ones</td>
<td>Mostly permanent materials: concrete, bricks</td>
</tr>
<tr>
<td>Roads</td>
<td>Unpaved</td>
<td>Unpaved</td>
<td>Paved</td>
</tr>
<tr>
<td>--------------</td>
<td>---------</td>
<td>---------</td>
<td>----------------</td>
</tr>
<tr>
<td>Water</td>
<td>Short of water supply</td>
<td>Lack of water supply</td>
<td>Insufficient water supply</td>
</tr>
<tr>
<td>Sewerage</td>
<td>Lack of sewerage, discharging directly into river</td>
<td>Lack of sewerage, discharging directly into reservoir or street</td>
<td>Insufficient sewage and maintenance</td>
</tr>
<tr>
<td>Sanitary</td>
<td>Rare Sanitary, discharging directly into river</td>
<td>Lack of sanitary, discharging directly into reservoir or street</td>
<td>Public sanitary, lacking for maintenance</td>
</tr>
<tr>
<td>Open Space</td>
<td>Rare open space, because of extremely-high building density</td>
<td>Rare open space, because of extremely-high building density</td>
<td>Rare open space, because of extremely-high building density</td>
</tr>
<tr>
<td>Interventions</td>
<td>Fundamental infrastructures are improved in slums, such as sanitary, drainage, waste disposal</td>
<td>New implements are proposed, and sustainable communities are built</td>
<td>Removed and replaced by new developments</td>
</tr>
</tbody>
</table>

*Table 4-7: Comparison of Urban Informal Settlements in Mumbai, Sao Paulo, and Beijing*

### 4.6 Conclusion

In conclusion, this chapter studied the urban informal settlement conditions and the regeneration projects proposed and implemented in Mumbai, India, Sao Paulo, Brazil, and Beijing, China. From the study, the regeneration of urban villages in Beijing can learn a short-term strategy of applying GI to improve the living conditions instead of removing the whole villages. The serious of GI techniques can supplement the conventional infrastructures and improve the conditions of drainage, sewerage, and sanitary. Consequently, the improvement of living conditions in urban informal settlements will affect on the urban hydrology positively and mitigate urban inland flooding problems.

The next chapter will select site(s) in Beijing and analyze the context and physical conditions of the site(s), to understand the challenges of stormwater management and the opportunities of applying GI in the urban villages.
5. Project Analysis of Dayouzhuang and Saoziying

This project selected on Dayouzhuang and Saoziying- two adjacent urban villages as a testing field. This chapter first introduces the criteria of selecting site(s) in Beijing. Second, the project analyzes the site conditions from the context, existing drainage and sewer system, impervious paving percentage, canopy coverage, land use, green space, and street network. From the analysis, the chapter concludes the challenges and opportunities of applying GI and creates a GI toolbox for Dayouzhuang and Saoziying.

5.1 Project Site Selection

The urban villages in Beijing were selected by the following guidelines.

First, the urban villages should represent the typical characteristics of urban villages. For example, they should be located at the skirt of Beijing Metropolitan Area (BMA), surrounded by urbanized developments, largely occupied by migrant residents. Moreover, their building density should be around 70%-90%, and FAR should be from 1.5-2.0. Typically, they do not have adequate infrastructure to support existing residents and have the potential problem of inland flooding.

Second, the urban villages should have enough data to work with, such as base map, topography, land use, existing vegetation, and building height and conditions, guaranteeing adequate information to analyze the feasibility of installing green infrastructures and evaluate the contribution of managing stormwater.

Third, the urban villages would be preferable if they were near major water resources. To create stormwater management system is to help improve the water infiltration and eventually restore
the regional hydrology. It is important to connect the urban villages to the major water resources to reinforce the benefits of GI.

Through understanding those guidelines in the context, the project selected the periphery of the northwest BMA. The area has several major water bodies and is the important underground water recharge area (Fig. 5-1, Fig. 5-2). Moreover, it is a rapidly developing area with large job markets and commercial activities. As the area is developing, around 70% of the original urban villages have been removed. The rest of the urban villages are waiting for the new policy and strategy.

From the remaining urban villages, Dayouzhuang and Saoziying have been selected as the test field of short-term urban village regeneration with GI. They are reported having issues with inland flooding as well as water shortage. The location of Dayouzhuang and Saoziying is represented as follows (Fig. 5-3).

Left: Figure 5-1 Underground Water System in BMA in Relation with Urban Village (Urban Village in China, 2008; Beijing Planning Institute, 2004)

Right: Figure 5-2 Surface Water System in BMA in Relation with Urban Villages (Beijing Urban Village Survey, 2008; Beijing Planning Institute, 2004)
5.2 Site Analysis

This section will analyze the existing conditions of the urban villages. All the information and data used in the site analysis come from three major sources. The first is the official plans from the Beijing Planning Institution and the Beijing Surveying and Mapping Bureau. The second is the estimation of the surrounding properties, the vegetation coverage, and the surface paving materials from Google Map. The third is the first hand experience from the site visit. The site photos will provide a direct feeling of what the sites look like. Based on the available information and data, the project conducts the site analysis as follows.

5.2.1 Site Context

Dayouzhuang and Saoziying are located on the edge of the northwest 5th Ring Road (Fig. 5-3). They are close to the Zhongguancun Technical and Business Center and enclosed by famous
educational institutions (Fig. 5-4). Beyond the 5th Ring Road, there is the Shangdi High Tech Industry Center as well as the extensive suburban commercial residential developments. Because of the huge demand of labor force, the area requires considerable cheap housings for the workers.

The public transportation is very convenient in this area. The Beigongmen Subway Station on Line 4 is on the south of the sites. Also, the Xiyuan bus terminal is right located on the southeast. There are many bus routes serving the sites (Fig. 5-5). Both of the subway station and the bus stops are in walking distance from the urban villages. The transportation meets the residents’ need of commuting.

Besides, there are two important historical landscape preservation site, the old royal gardens Yuanming Yuan(Old Summer Palace) and Yihe Yuan(Summer Palace) (Fig. 5-4). They are the popular destinations for citizens in the holidays.

![Figure 5-4 Surrounding Properties of Dayouzhuang and Saoziying](image-url)
Figure 5-5 Transportation Analysis of Dayouzhuang and Saoziying

5.2.2 Hydrology

The sites are located in the area used to have numerous of natural artesian spring. Ponds and lakes from the springs and streams from the northwest hills and mountains provided abundant water resources for the area. The natural water bodies are changed because of the urban development. Nowadays, the important water bodies in the area include the channelized Qinghe River, the Jingmi Division Channel, and the water systems of Yihe Yuan and Yuanming Yuan.
Qinghe River was once a natural river in the city. It runs across Haidian, Chaoyang, and Changping three major BMA districts. Now it is channelized and transformed to the major drainage canal in north of the BMA.

Jingmi Division Channel is one of the main arteries of Beijing water supply system. It transfers the water from the Miyun Reservoir in the suburban districts to the BMA, supporting the urban residential and industrial water use. In order to rapidly transport the water and guarantee the water quantity, the Jingmi Division Channel was built with impervious materials to reduce the water infiltration consumption during the transportation.

Yihe Yuan and Yuanming Yuan were built about 300 years ago. The Yihe Yuan water system has a natural lake "Kunming Lake". The area of the lake is about 220ha. It serves as an important
reservoir for storing the water from hills and mountains in the northwest of BMA. The Yuanming
Yuan water system covers the whole land area of around 250ha, composed by several ponds and
lakes at multi-sizes.

Those lakes were a gift from nature, but now they cannot be sufficiently supported because of the
decreasing groundwater level. Now, the Kuming Lake is relying on the water from the Miyun
Reservoir to retain the water level. Ironically, Yuanming Yuan implement an impervious surface
on the lakebed, preventing water infiltrating into the ground to retain the water level.

This area was an important groundwater recharging area, but affected by the urbanization, the
natural water cycle was greatly disturbed. The decreasing infiltration not only affects the city’s
water supply but also leads to urban inland flooding. The next section will analyze the drainage
conditions in Dayouzhuang and Saoziying and discuss how stormwater performs in the urban
villages.

5.2.3 Municipal Water System and Site Water Flow

The city’s water system planning includes water supply, sewerage, rainwater, and recycling water.
The site area is currently supported by the city sewerage system, and will be supported by the
recycling water system in plan (Fig. 5-7, Fig. 5-8). Around the site, there are sewerage pipes
along the North 5th Ring Road, the Yuanmingyuan West Road, and the Yiheyuan Road.
Recycling water pipes are planned to be built along the Yuanmingyuan West Road. The treatment
plant of sewerage and recycling water is located in the northeast of the site (Fig.5-8).
The city-scale water system plan does not include the particular information on the water treatment system in the site. From the site observation, the urban villages are using the combined sewerage and stormwater management system. The stormwater is collected by the catch basins on the street sides and transferred by the water pipes. The villages lack a separated stormwater management system.

The site has a flatly graded urban landscape (Fig. 5-9). Overall, in the site area defined by the North 5th Ring Road, the Yuanmingyuan West Road, and the Yiheyuan Road, the stormwater flows from the properties to the water pipes along the city main roads. According to the spot elevations, the valley, where water from the urban villages majorly gathered, is located on the Dayouzhuang Market Road, the Central Market Road, and the East Saoziying Road. Because the urban villages lack an effective stormwater management system, the valley streets are at the high risk of inland flooding during heavy rainstorms.
5.2.4 General Information

Dayouzhuang and Saoziying are two villages belonging to Qinglongzhen Administration Government. Dayouzhuang is composed by the west part and the east part. Two parts are separated. Only the east part is selected as the project site, which is adjacent to Saoziying. The residents are primarily composited by young adults at working age. The general site information is listed below.

<table>
<thead>
<tr>
<th></th>
<th>Dayouzhuang (East Part)</th>
<th>Saoziying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>14ha</td>
<td>16ha</td>
</tr>
<tr>
<td>Area per person</td>
<td>36 ㎡/person</td>
<td>26 ㎡/person</td>
</tr>
</tbody>
</table>

*Table 5-1 General Information of Dayouzhuang and Saoziying*
The natural infiltration process of stormwater in the villages is disturbed by the high percentage of impervious pavements. In addition, the low canopy coverage has little capability to hold the raindrops and slow down their speed. Those conditions increase the flooding possibility. The following sections will analyze the urban villages’ land use, building conditions, street network to further understand the urban village characteristics and the drainage problem.
Table 5-2 Existing Stormwater Drainage Condition Attributes

<table>
<thead>
<tr>
<th></th>
<th>Dayouzhuang</th>
<th>Saoziying</th>
<th>Environment (outside the urban villages)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building density%</td>
<td>63.1%</td>
<td>70.6%</td>
<td>23.9%</td>
</tr>
<tr>
<td>Canopy coverage %</td>
<td>16.9%</td>
<td>6.4%</td>
<td>23.9%</td>
</tr>
<tr>
<td>Impervious paving (%total area)</td>
<td>36.9%</td>
<td>29.4%</td>
<td>29.2%</td>
</tr>
<tr>
<td>Impervious paving (%total surface area)</td>
<td>100%</td>
<td>100%</td>
<td>38.4%</td>
</tr>
<tr>
<td>Area for GI %</td>
<td>5.6%</td>
<td>2.1%</td>
<td>58.7%</td>
</tr>
</tbody>
</table>

5.2.5 Land Use

The dominant land use of Saoziying and Dayouzhuang is residential (Fig. 5-12). The combined residential commercial is along the major connecting streets. Those stores, such as restaurants, groceries, pharmacies, web surfing, support residents’ daily needs. Along the Central Dayouzhuang Street, street vendors and retailers occupy the sidewalks on the north side. They sell fresh fruits, vegetables, and other foods. Sometimes they also offer bottle and paper recycling.
service. There are two public activity areas in the urban villages. They are around the corners of the Central Dayouzhuang Street. They have simple outdoor fitness facilities and beloved by people.

Overall, the urban villages are lively developing. The sites are mostly covered with hard materials and have little green space. The next section will analyze other potential green spaces in the urban villages.
5.2.6 Green Space

From the analysis of tree canopy and impervious pavements, we can know the site does not have much green space (Fig. 5-11). However, in the residential area, many houses have planters for herbs and flowers at the entrance (Fig. 5-14). Some of them even plant vegetables and fruits. In short, small-scale gardening is popular in the villages. This could be an opportunity for new green spaces. The next section will analyze the conditions of the buildings to find more opportunities for GI.
5.2.7 Building Conditions

The buildings in the urban villages include three different types: traditional buildings, self-reconstructed buildings, and high-rise buildings (Fig. 5-15; Fig. 5-16). The traditional buildings are the original style of residential buildings in villages. They usually are one-story buildings with pitched roofs.

The self-reconstructed buildings are usually three-story buildings. They are built by brick and concrete. The high-rise buildings are six-story apartments built by the authorities, named Saoziying Courtyards. Compared to the rest of the urban villages, they are better supported by infrastructure. They have their own parking lots and individual sanitary.

Moreover, there are a few self-constructed temporary buildings for storage and commercial use. The temporary buildings are usually built in two circumstances. One is in the yard enclosed by
the traditional buildings as a part of the unauthorized building increments. Another is in the streets, providing shelters for self-driven commercial activities. The temporary buildings are usually one story and built by plastic materials.

In conclusion, the buildings arrangement is not systematical because of the overwhelming of spontaneous developments. The site visit provides the general idea but it is not accurate because of lacking detailed data. Generally speaking, the building conditions are suitable for GI implementation. The building material is substantial and the roofs of reconstructed buildings are flat. Both characteristics are good to support the structure of roof gardens. The next section will analyze the urban villages from the streets.

![Traditional buildings](image1)
![Self-reconstructed buildings](image2)

![High-rise residential buildings](image3)
![Temporary buildings](image4)

*Figure 5-16 Photos of Existing Building Conditions (Taken by Feiqiang Tong)*
5.2.8 Street Network

Figure 5-17 Existing Street Network

The street network in the urban villages has four hierarchies (Fig. 5-17).

The first is the double lane, two-way vehicle streets (Fig. 5-18). Only the South Dayouzhuang Street is belonged to this hierarchy. It goes from the south gate of Dayouzhuang to the side gate of Central Party School. The street width is 9m.

The second is the single lane, two-way vehicle streets (Fig. 5-19). The width of the streets is largely determined by the setback of the buildings, which is usually 4-5.5m. This category includes 1) the Central Dayzouhuang Street, the Central Market Street, and the East Saoziying Street—the commuting road from the side gate of Central Party School to the gate of Saoziying at Yuanmingyuan West Road, 2) the Saoziying Courtyard Drive— the driveway connecting to the Saoziying Courtyards from the Dayouzhuang Road, 3) the Saoziying Residents’ Committee
Drive— the driveway connecting to the Saoziying Residents' Committee from the Beijing University Yanbeiyuan east gate at the Yuanmingyuan West Road, and 4) the Minor Residential Drive in Dayouzhuang.

Because the property walls limit the access to the urban villages, there is only one major commuting street from the south gate of Dayouzhuang to the east gate of Saoziying. The streets are crowded with traffic, especially the Central Dayouzhuang Street and the East Saoziying Street, because they are narrower than the South Dayouzhuang Street. As the geographic center of the urban villages, the Central Dayouzhuang Street and the East Saoziying Street is overwhelmed by cars, tricycles, bicycles, street vendors, retailers, and people. It makes the lively but crowded streetscape.

The third is the pedestrians. The width of the pedestrians is usually less than 3m wide (Fig. 5-20). Most of the streets in the urban villages are belong to this category. They are sided by residential or combined residential commercial land use, and goods are stored on the side of the street.

The fourth is the alleys between a building and a building. The width of the alleys could be less than 1m. They are hardly visible from the main streets, and only allow one person walking through (Fig. 5-21). The alleys are hard to recognize from the existing information, and therefore they are not marked on the Existing Street Network map.

In summary, the street space in the urban villages is very limited. The vehicle streets are occupied by traffic, authorized parking, commercial activities, and people. The pedestrians are largely used as front yards or storage areas. The streets from the Central Dayouzhuang Street to East Saoziying Street are overwhelmed by traffic and human activities. Because of the high risk of inland flooding in this part, an effective approach is needed to balance the human activities and stormwater management.
Double Lanes, Two-way Vehicle Street (9m)
A-A’

South Dayouzhuang Street
Figure 5-18 1st Hierarchy: Double Lane, Two-way Vehicle Street

Single Lane, Two-way Vehicle Street (4-5.5m)
B1-B1’

Central Dayouzhuang Street
2. Central Market Street

3. East Saoziying Street
4. Saoziying Courtyard Drive

5. Minor Residential Drive

Figure 5-19 2nd Hierarchy: Single Lane, Two-way Vehicle Street
Pedestrians in Residential and Combined Residential Commercial Land Use

Figure 5-20 3rd Hierarchy: Pedestrians
5.3 Challenges and Opportunities of Applying GI

The site faces several challenges and opportunities of applying green infrastructures. In terms of the requirements of applying GI, the site conditions are identified as follows.

Challenges:

1. The building density in the site is very high, around 70% of the entire village area. Moreover, the chaotic organization divides the spare space to small pieces and leaves only around 10% available space for GI interventions. Therefore, green roofs would be the important strategy in this project. They can help increase the infiltration area, purify
the pollutants, and slow the stormwater flow. Pervious pavements would be another important strategy. Replacing existing impervious pavements in parking lots, sidewalks, and pedestrians, will greatly increase the infiltration area and help reduce the stormwater quantity. Cisterns could also be an feasible approach, because they can be installed underground, and therefore do not occupy the street space.

2. Moreover, in such a dense density, there are lots of human activities happening in the sites, and therefore GI should provide services other than managing stormwater. For example, community gardens, not only could help filter and infiltrate stormwater, but also create outdoor open spaces. Community gardens would also bring economic benefits to the urban villages.

3. The stormwater in the urban villages are contaminated from the vehicles, unorganized restaurants, and daily life, which requires GI could purify specific pollutants. For example, rain gardens and infiltration trenches could considerably help improve filtration. Pervious pavements also could provide filtration in a medium level.

4. The water flow is concentrated in the inner village streets: the Central Dayouzhuang Street, the Central Market Street, and the East Saoziying Street. Those streets does not have outlets to drain the stormwater to the municipal water system on the city main streets, and therefore the stormwater drainage only relies on the aged village infrastructure, which is not very efficient. This leads easily to inland flooding.

**Opportunities:**

1. The sites also have the advantages such as the substantial building structure. The reconstructed buildings, both high-rise and low-rise are built by concrete and bricks. Those buildings are more suitable for installing green roofs than the traditional buildings with pitch roofs.
2. The sites have the culture of gardening. There are many family having planting beds on their small front yards. Moreover, the area, where the sites are located, has suitable conditions for plant growth. The sites are located nearby the historical landscape conservation area. Also, the properties around the sites have a high percentage of canopy cover. Both indicate a good condition for plant growth.

In summary, substantial building structure and suitable soil conditions make installing GI feasible in the sites. Moreover, the limited space and heavy human activities require GI can save space and support multiple uses. The next section will discuss the GI technics that meet the requirements.

5.4 Green Infrastructure Toolbox

Based on the site analysis, a GI toolbox is created for the specific conditions. The toolbox learns from *San Francisco Stormwater Design Guideline*, *Rooftops to Rivers, the Value of Green Infrastructure*, and *Sao Paulo is Calling* project (See full citation in Reference). The estimations in the toolbox are based on the project context.

The selected GI tools attempt to meet the requirements of stormwater management and the constraints of installing green infrastructure. The GI toolbox considers green roofs and green walls as the major technic, because they could greatly increase planting area but do not require much space for installation. Rain barrels also are the major component in the toolbox. They are cheap and easy for installation, but could effectively improve the stormwater storage and recycling. GI toolbox also proposes to use permeable pavements and cisterns. They could help increase the infiltration area and the storage capability of the sites without occupying the street spaces for people activities.
The GI toolbox has four tables. The first two focus on the GI's functions in controlling quantity and quality of stormwater. Controlling quantity shows the capability of GI in reducing stormwater volume by infiltration, storage and evapotranspiration. Controlling quality shows their capability of removing typical pollutants from the stormwater.

### Quantity Control

<table>
<thead>
<tr>
<th></th>
<th>Infiltration</th>
<th>Storage</th>
<th>Evapotranspiration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pervious pavements</td>
<td>○</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tree planting</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Green roofs</td>
<td></td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Green walls</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Rain gardens</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Infiltration trenches</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Cisterns</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td>Rain barrels</td>
<td></td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>Public green spaces</td>
<td>○</td>
<td></td>
<td>○</td>
</tr>
<tr>
<td>(community garden, activity area)</td>
<td>○</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5-3GI in Stormwater Quantity Control (From San Francisco Stormwater Guidelines, 2010)*

×: poor ○: okay √: good

### Quality Control

<table>
<thead>
<tr>
<th></th>
<th>Metals</th>
<th>Sediments</th>
<th>Trash</th>
<th>Oil and Grease</th>
<th>Organics</th>
<th>Nutrients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pervious pavements</td>
<td>○</td>
<td>√</td>
<td>×</td>
<td>×</td>
<td>○</td>
<td>√</td>
</tr>
<tr>
<td>Tree planting</td>
<td>√</td>
<td>√</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>Green roofs</td>
<td>√</td>
<td>√</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>Green walls</td>
<td>√</td>
<td>√</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>Rain gardens</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Infiltration trenches</td>
<td>√</td>
<td>×</td>
<td>×</td>
<td>√</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Cisterns</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain barrels</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Public green spaces</td>
<td>√</td>
<td>√</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>×</td>
</tr>
<tr>
<td>(community garden, activity area)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 5-4GI in Stormwater Quality Control (From San Francisco Stormwater Guidelines, 2010)*
The third table shows the requirements of installing GI in a qualitative way. The fourth table shows the ecosystem services and landscape functions that GI provides.

<table>
<thead>
<tr>
<th><strong>Installation Constrains</strong></th>
<th><strong>Space</strong></th>
<th><strong>Construction</strong></th>
<th><strong>Cost</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pervious Pavement</td>
<td>Large (to be effective)</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Tree Planting</td>
<td>Medium</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Green Roof</td>
<td>Small</td>
<td>Roof structure support</td>
<td>High</td>
</tr>
<tr>
<td>Green Wall</td>
<td>Small</td>
<td>Wall structure support</td>
<td>Low</td>
</tr>
<tr>
<td>Rain Garden</td>
<td>Medium</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Infiltration Trench</td>
<td>Large (to be effective)</td>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Cistern</td>
<td>Small (underground)</td>
<td>Land support</td>
<td>High</td>
</tr>
<tr>
<td>Rain Barrel</td>
<td>Medium</td>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>Public green space (community garden, activity area)</td>
<td>Large</td>
<td>Fertile soil</td>
<td>High</td>
</tr>
</tbody>
</table>

*Table 5-5 Installation Constrains of GI (Value of Green Infrastructure, 2011)*

<table>
<thead>
<tr>
<th><strong>Ecosystem Services and Landscape Functions</strong></th>
<th><strong>Supporting Human Activities</strong></th>
<th><strong>Improving air quality</strong></th>
<th><strong>Protecting biodiversity</strong></th>
<th><strong>Improving hydrology</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pervious Pavement</td>
<td>Parking, pedestrian</td>
<td>Low</td>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td>Tree Planting</td>
<td>Viewing, shading</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Green Roof</td>
<td>Building conditioning</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Green Wall</td>
<td>Building conditioning</td>
<td>Good</td>
<td>Good</td>
<td>Okay</td>
</tr>
<tr>
<td>Rain Garden</td>
<td>Viewing, entertaining</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Infiltration Trench</td>
<td>Parking, pedestrian</td>
<td>Low</td>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td>Cistern</td>
<td>Flushing toilets, irrigating plants</td>
<td>Low</td>
<td>Low</td>
<td>Okay</td>
</tr>
<tr>
<td>Rain Barrel</td>
<td>Flushing toilets, irrigating plants</td>
<td>Low</td>
<td>Low</td>
<td>Okay</td>
</tr>
<tr>
<td>Public green space (community garden, activity area)</td>
<td>Cultivating, viewing, entertaining</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
</tr>
</tbody>
</table>

*Table 5-6 Ecosystem and Landscape Services of GI (Value of Green Infrastructure, 2011)*
5.5 Conclusion

In conclusion, the selected sites are the typical urban villages in Beijing at the high risk of urban inland flooding. The sites have high percentage of impervious paving and low percentage of canopy coverage, which is not good for stormwater infiltration and drainage. Moreover, the existing drainage infrastructure does not meet the current demand. To install GI, the sites have the challenges of inadequate available space and heavy human activities, but they also have the opportunities of substantial building structure and suitable planting soil. According to that, the GI toolbox proposes to use GI that does not require much space and support multiple activities. The selected GI include pervious pavements, rain gardens, tree planting, infiltration trenches, rain barrels, cisterns, green roofs, green walls, and community gardens. The next chapter will use the GI toolbox to create GI alternatives for the sites.
6. Project Proposal

Based on the challenges and opportunities concluded in the site analysis, this chapter will propose a stormwater management system for the sites. Guided by the stormwater management system, this chapter will create two GI alternatives: low intervention plan and high intervention plan. The chapter will evaluate two alternatives in terms of the area change of GI technics. The measurable GI technics include pervious pavements, tree canopy, open spaces, and green roofs. At the end, the project will compare the two alternatives with the exiting conditions, to find out if the GI applications could practically increase the sites’ capability of managing stormwater.

6.1 Stormwater Management System

Based on the analysis, the project proposes the stormwater management system for the urban villages. The system is composed of GI improvements on buildings, streets, and publics (Table 6-1). The GI improvements form the stormwater management veins along the streets to control the stormwater flow (Fig. 6-1). The process starts from rooftops. The green roofs hold and treat the stormwater. The flows from the roofs would merge into the water flow on streets, infiltrating into the ground through rain gardens, infiltration trenches, and pervious pavements. Also, the flows from the streets would collect in the cisterns and only the overflow would discharge to the municipal water pipes. In short, the system attempts to control the stormwater at sources as much as possible.

<table>
<thead>
<tr>
<th>GI Improvements on Buildings, Streets, and Public Spaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
</tr>
<tr>
<td>Green roofs</td>
</tr>
<tr>
<td>Green walls</td>
</tr>
<tr>
<td>Rain barrels</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Streets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green roofs</td>
<td>Pervious pavements, including pavements on the sidewalks, parking lots, driveways, and alleys</td>
</tr>
<tr>
<td>Green walls</td>
<td>Rain gardens, including bio-retention planters</td>
</tr>
<tr>
<td>Rain barrels</td>
<td>Tree planting</td>
</tr>
</tbody>
</table>

In short, the system attempts to control the stormwater at sources as much as possible.
<table>
<thead>
<tr>
<th>Buildings</th>
<th>Streets</th>
<th>Public space</th>
<th>Activity areas</th>
<th>Community gardens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Roof</td>
<td>Pervious Pavement</td>
<td>Cisterns</td>
<td>Activity areas</td>
<td>Community gardens</td>
</tr>
<tr>
<td>Green Wall</td>
<td>Rain Garden</td>
<td>Infiltration trenches, bordering parking lots</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rain Barrel</td>
<td>Infiltration Trench</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 6-1 GI Improvements on Buildings, Streets, and Public Spaces**

**Figure 6-1 Stormwater Management Veins**

The stormwater management system is classified to the major veins and the minor veins (Fig. 6-2). The hierarchy of the veins is determined based on the street width, usage, and the water flow. The major veins include the South Dayouzhuang Street, the Central Dayouzhuang Street, the Central Market Street, the East Saoziying Street, the Saoziying Courtyard Driveway, the Saoziying Resident’s Committee Driveway, the south entrance area of Dayouzhuang and the north entrance area of Saoziying. The minor veins include the minor driveways in the residential areas, the pedestrians, and the alleys. The minor veins extend the stormwater management system throughout the urban villages.

In this system, the major veins are the frequently used streets and connect the important destinations in the urban villages. Those destinations include the market areas, the activity areas, the Saoziying Courtyards, the Dayouzhuang Residents’ Committee, the Saoziying Residents’ Committee, and the gates of the urban villages. The major veins attempt to support activities such as entertaining, walking, parking, and gardening.
Besides, the major veins are to connect the minor veins to the municipal water system. Especially, the valley streets—the Central Dayouzhuang Street, the Central Market Street and the East Saoziying Street—attempt to reduce the peak hour flow and prevent inland flooding. In addition, the major veins also attempt to manifest and celebrate stormwater.

By building the stormwater management system, the project attempts to create a structure of green infrastructure in the urban villages. The next section will introduce the two GI alternatives.

![Fig 6-2 Proposed Stormwater Management System in Dayouzhuang and Saoziying](image)

### 6.2 Green Infrastructure Alternatives

Two GI alternatives are proposed to create the stormwater management system: “low-intervention” alternative A and “high-intervention” alternative B. The alternative A is planning to control the intervention level as well as the cost by limiting building removal up to 2%. The alternative B is planning to allow a medium-level intervention and achieve the best performance by increasing building removal to 15%. In the evaluation, the area of each GI technics will be
used to measure the improvements, mainly including pervious pavements, tree canopy, and green roofs.

6.2.1 Green Infrastructure Alternative A

The alternative A accepts the existing conditions and limits the building removal up to 2% of the total site area. The building density is slightly reduced to 65%. The removal focuses on the self-reconstructed buildings in the market areas. The buildings are rebuilt in a smaller footprint but remain the existing FAR to providing enough housing. The alternative A improves the existing activity area and develops the entry plazas, attempting to increase the open space to 2%. Within 2% removal, the alternative A merely increases the 11.3% canopy coverage to 15.0%. The pervious pavements are proposed to use on the traffic streets and the main pedestrians, attempting to increase the pervious paving surface to 20% of the total site area. Based on the building conditions, there are about 20% of the buildings with the substantial structure for roof gardens. The alternative A attempts to transform 15% of them to green roofs. The total GI area is planning to increase to 37% of the total site area. The estimation and evaluation of Alternative A is listed in the following table. The next section will introduce the regeneration details of the important streets in major veins and minor veins.

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Estimated</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention Area</td>
<td>-</td>
<td>2%</td>
<td>1.7%</td>
</tr>
<tr>
<td>Building density</td>
<td>67.1%</td>
<td>65%</td>
<td>66.6%</td>
</tr>
<tr>
<td>FAR</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Open space</td>
<td>0.2%</td>
<td>2%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>11.3%</td>
<td>15%</td>
<td>15.5%</td>
</tr>
<tr>
<td>Pervious pavements</td>
<td>-</td>
<td>20%</td>
<td>18.3%</td>
</tr>
<tr>
<td>Green Roofs</td>
<td>-</td>
<td>15%</td>
<td>18.1%</td>
</tr>
<tr>
<td>GI Area</td>
<td>-</td>
<td>37%</td>
<td>38.0%</td>
</tr>
</tbody>
</table>

Table 6-2 Comparison of Metrics of Existing, the Estimated and the Final Plan A
6.2.1.1 Major Veins

As mentioned in the stormwater management system, the purpose of the major veins is to manage the concentrated overflow, to mitigate the traffic, and to support the commercial activities. According to the purpose, this section will mainly introduce the improvements on the important streets of major veins. They are the South Dayouzhuang Street, the Central Dayouzhuang Street, the Central Market Street, the East Saoziying Street, and the Saoziying Courtyard Drive.

1) South Dayouzhuang Street

In the alternative A, the project completes the street trees in the South Dayouzhuang Street, creating a green corridor leading people from the south gate to the market streets. The sidewalk pavements are improved and replaced with pervious pavements. The street parking lots are repaved with porous planting materials. According to the water flow, the infiltration trenches are installed on the west side of the street, connecting to the underground cisterns. The suitable
residential houses are equipped with roof garden. A downspout discharges the stormwater from roofs to the rain barrels in the yard.

![Diagram of residential houses with roof garden and stormwater management system]

2) Central Dayouzhuang Street

To mitigate the crowded traffic condition on the Central Dayouzhuang Street, the alternative A proposes to extend the street space by rebuilding the buildings along the street in a smaller footprint. This improvement changes the existing single vehicle lane to the double vehicle lanes, with the temporary street parking on the south side of the street.

*Figure 6-4 GI Improvements in South Dayouzhuang Street*
The existing street is repaved with the permeable bricks to calm the traffic and improve the walking experience. The sidewalks and vending area are repaved with pervious materials as well. The vending area is elevated to separate from the street traffic. The property walls are planted with vines. Infiltration trenches border the street parking lots. The extended sidewalks provide space for rain gardens. They are to filter the pollutants from vehicles. They also connect to the cisterns to store the stormwater. The rain gardens manifest the stormwater and educate people with the beautiful stormwater management technic.

Figure 6-5 GI Improvements in Central Dayouzhuang Street
3) Central Market Street

The existing activity area is redeveloped into the green space, paved with permeable bricks. The rain gardens separate the activity area from the traffic. The old temporary building for market use is rebuilt to a two-story concrete building, providing more room for small business. The building roof changes to the green roof with a downspout connecting to the rain barrels.

*Figure 6-6 GI Improvements in Central Market Street*
4) East Saoziying Street

The combined residential commercial buildings are rebuilt in a smaller footprint. New sidewalks are added in front of the buildings. The new buildings have gardens on the top and rain barrels in the backyards. The rain gardens are proposed on the sidewalks to retain and manifest the water. The driveway is repaved with permeable bricks to increase the infiltration and calm the traffic. The parking lots are also repaved. The property walls are planted with vines.

*Figure 6-7 GI Improvements in East Saoziying Street*
5) Saoziying Courtyard Drive

As the spatial extension of the Central Market Street, the Saoziying Courtyard Drive is also occupied with commercial activities. The proposed GI improvements are to increase the infiltration and to improve the commercial environment. These include repaving the street, elevating the vending area, and redeveloping the rooftops. The property walls are also planted with vines.

Figure 6-8 GI Improvements in Saoziying Courtyard Drive

6.2.1.2 Minor Veins

In alternative A, the minor veins include the Minor Dayouzhuang Residential Drive and the main pedestrians of the urban villages. The purpose of redeveloping the minor veins is to increase the infiltration and to reinforce the daily experience of GI technics. This section will take the Minor Dayouzhuang Residential Drive and a typical pedestrian street as the examples to introduce the improvement details.
1) Dayouzhuang Minor Residential Drive

The Minor Resident Drive is the major vehicle connection from the South Dayouzhuang Street to the residential areas in Dayouzhuang. The alternative A proposes to replace the existing pavements to permeable bricks, to create a walking-friendly environment. Moreover, trees and shrubs are planted in the front yard gardens. Also each family is encouraged to have rain barrels in its backyards to collect stormwater for irrigation.

*Figure 6-9 GI Improvements in Minor Residential Drive*
2) Pedestrian Streets

The pedestrian streets are similar to the Dayouzhuang Minor Residential Drive. The improvements include replacing the pedestrian pavements, developing front yard gardens, and implementing rain barrels. Moreover, the roof gardens are proposed on the buildings with a stable structure and a flat roof.

![Imagery of green infrastructure improvements]

Figure 6-10 GI Improvements in Pedestrians

6.2.2 Green Infrastructure Alternative B

The alternative B allows the building removal to 15% and reduces the building density to 60% of the total site area. The building removal still focuses on the self-reconstructed buildings in the combined residential commercial area. Those buildings are proposed to be redeveloped at a smaller footprint but keep the FAR at 1.0. By redeveloping the building clusters, the alternative B creates four urban village centers: the Central Combined Residential Commercial Center, the Saoziying Commercial Center, the South Gate Commercial Center, and the North Gate Residential Center.

The alternative B also removes the temporary buildings scattered in the residential area, transforming into pocket parks. This attempts to increase the open space to 5%. The
improvements of open space also include the activity areas and the community garden. As the open space increases, the canopy coverage also increases to 20% of the total site area.

By removing the temporary buildings, the pedestrian network is improved. The new pedestrians associated with the wide alleys are repaved by permeable bricks. Therefore, the pervious pavements are expected to increase to 25%. The green roof percentage increases to 30%, including all the existing buildings with the suitable structure and the redeveloped buildings. In alternative B, the total GI area is planned to reach 57%, over half of the site area. The estimation and evaluation of alternative B is as below (Table 6-3). The next section will introduce the improvement details in alternative B.

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Estimated</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervention Area</td>
<td>-</td>
<td>15%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Building density</td>
<td>67.1%</td>
<td>60%</td>
<td>60.2%</td>
</tr>
<tr>
<td>FAR</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Open space</td>
<td>0.2%</td>
<td>5%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>11.3%</td>
<td>20%</td>
<td>18.8%</td>
</tr>
<tr>
<td>Pervious pavements</td>
<td>-</td>
<td>25%</td>
<td>24.7%</td>
</tr>
<tr>
<td>Green Roofs</td>
<td>-</td>
<td>30%</td>
<td>27.1%</td>
</tr>
<tr>
<td>GI Area</td>
<td>-</td>
<td>60%</td>
<td>57.0%</td>
</tr>
</tbody>
</table>

*Table 6-3 Comparison of Metrics of Existing, Estimated, and Final Alternative*
6.2.2 Major Veins

This section will introduce the GI improvements in the alternative B from the important streets of the major veins and the minor veins. The alternative B further develops the major veins. The South Dayouzhuang Street, the Central Dayouzhuang Street, the Central Market Street and the East Saoziying Street still are the major vehicle connection in the urban villages. Moreover, there are several new improvements. First, the alternative B proposes to build community gardens on the removed area on the Saoziying Courtyard Drive. Second, the alternative B proposes to transform the single one-story buildings to one combined building complex with an enclosed yard. Learned from the traditional architecture style “Siheyuan”, this building form creates a central public open space for outdoor activities. Third, the alternative B proposes to increase the area of rain gardens, creating a continuing manifestation of stormwater along the South Dayouzhuang Street, the Central Dayouzhuang Street, the Central Market Street, and the East Saoziying Street. In addition, to maximize the effect of the 15% building removal, the project focuses on buildings
on the major veins. The major rebuilt areas are the Central Dayouzhuang Street commercial area, the East Dayouzhuang Street commercial area, the commercial area at south gate, and the residential area at north gate.

1) South Dayouzhuang Street

Compared with that in the alternative A, the South Dayouzhuang Street in the alternative B implement rain gardens on the both sides of the road, increasing the capacity of infiltration and retainment.

Figure 6-12 Section and Water flow of South Dayouzhuang Street
2) Dayouzhuang Commercial Center

The Dayouzhuang Commercial Center is composed by the Central Dayouzhuang Street and the Central Market Street. The Central Dayouzhuang Street is one of the major rebuilt areas in the alternative B. The existing combined residential commercial buildings are transformed to the building complexes. The building complex is designed to the structure of two-story height. The first story is commercial use and the second story is residential use. For each complex, there is an enclosed central yard. The central yard provides the public open space with planted rain gardens. Moreover, along the sidewalks, water tolerant trees are planted in the rain gardens to increase the canopy area.

*Figure 6-13 Section of Central Dayouzhuang Street*
Also in the Central Market Street and the East Dayouzhuang Street, water tolerant trees are planted in the rain gardens.

Figure 6-14 Section of Central Market Street
2) Saoziying Commercial Center

The Saoziying Commercial Center is composed by the East Saoziying Street and the Saoziying Courtyard Drive. In the East Saoziying Street, water tolerant trees are planted in the rain gardens. Other GI improvements are similar to that in alternative A.

Figure 6-15 Section of East Saoziying Street

On the Saoziying Courtyard Drive, a community garden is proposed on the original site of several temporary buildings next to the Courtyard #1. The alternative B also creates a farms’ market
place associated with the community garden. The previous street vending area is transformed to the parking lots to meet the market’s need.

6.2.2.2 Minor Veins

The GI improvements on the minor drive and the pedestrians keep the same as what is proposed in alternative A. However, pocket parks are proposed along the pedestrian in alternative B to increase the activity area and form small infiltration areas.
In summary, the alternative B provides an advanced stormwater management system by increasing the percentage of green roofs, creating more green spaces, and involving local agriculture. The four urban village centers and the continuing streetscape from the South Dayouzhuang Street to the East Saoziying Street represent the image of the urban villages in the future. The next section will evaluate the two alternatives and discuss the GI improvements in each alternative.
6.2.3 Evaluations and Comparison of Alternative A and B

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Alternative A</th>
<th>Alternative B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site Intervention%</td>
<td>-</td>
<td>1.8%</td>
<td>14.6%</td>
</tr>
<tr>
<td>Building density</td>
<td>67.1%</td>
<td>66.6%</td>
<td>60.2%</td>
</tr>
<tr>
<td>FAR</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Open spaces</td>
<td>0.2%</td>
<td>1.1%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Canopy coverage</td>
<td>11.3%</td>
<td>15.5%</td>
<td>18.8%</td>
</tr>
<tr>
<td>Pervious pavements</td>
<td>-</td>
<td>18.3%</td>
<td>24.7%</td>
</tr>
<tr>
<td>Green Roofs</td>
<td>-</td>
<td>18.1%</td>
<td>27.1%</td>
</tr>
<tr>
<td>GI Area</td>
<td>-</td>
<td>38.0%</td>
<td>57.0%</td>
</tr>
</tbody>
</table>

Table 6-4 Comparison of GI Improvements in Alternative A and B (Measured by Area Percentage)

<table>
<thead>
<tr>
<th></th>
<th>Existing</th>
<th>Alternative A</th>
<th>Alternative B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain gardens</td>
<td>-</td>
<td>Least</td>
<td>Average</td>
</tr>
<tr>
<td>Infiltration trenches</td>
<td>-</td>
<td>Least</td>
<td>Average</td>
</tr>
<tr>
<td>Cisterns</td>
<td>-</td>
<td>Average</td>
<td>Average</td>
</tr>
<tr>
<td>Rain barrels</td>
<td>-</td>
<td>Most</td>
<td>Most</td>
</tr>
</tbody>
</table>

Table 6-5 Comparison of GI Improvements in Alternative A and B (Measured by Relative Quantity)

The Table 6-4 is based on the GI whose metrics are measurable on the map. In the context of the individual sites, the area of rain gardens and infiltration trenches are too small to take into account. Therefore they are only estimated and included in the total GI area. The Table 6-5 is based on the GI whose metrics can only be measured in qualitative, comparative terms. Beside rain gardens and infiltration trenches, the cisterns and rain barrels, which are volume-based techniques, are also included in Table 6-5.

The GI alternative A rebuilt 1.8% area of the total site, while the GI alternative B rebuilt 14.6%. With the increasing of the intervention area, the building density reduced from 67.1% to 60.2% in alternative B. Therefore, the open space percentage increased from 1.1% in alternative A to 5.2% in alternative B. The area of canopy cover and pervious pavements also increased from
alternative A to B. In alternative A, the canopy coverage increased to 15.5%, and in alternative B it increased to 18.8%. Similarly, the percentage of pervious pavements in the alternative B was increased to 24.7% from 18.3% in the alternative A. Also, the rain gardens and infiltration trenches in the alternative A were less than that in the alternative B. The GI techniques listed above are all strongly affected by the space that increased by removing and rebuilding some existing buildings. This GI is primarily limited by the space.

However, the cisterns and rain barrels are not strongly affected by the available space. The cisterns are installed underground, which required a large amount of engineering work but a little street space. Therefore they were proposed equally in the alternatives, but limited by the requirement of storage capacity. Comparatively, the rain barrels are largely equipped in the alternatives. Because they are easy but effective installation for water storage, each building was proposed to have at least one rain barrel to collect rainwater from roofs. In this context rain barrels are the most cost-and-space effective form of GI.

Notably, the green roofs area was doubled from the alternative A to B. As the intervention percentage increased, the green roof percentage increased from 18.1% to 27.4%, contributing about half of the GI area respectively in alternative A 38.0% and B 57.0%. From the area statistic we can claim that green roofs are the most effective GI technique in the regeneration plan. This is because the installation of green roofs is not limited by the earth space. They provide another possibility of GI improvements in the high-density communities. It is important to note, however that green roofs are also the most costly GI practice, and may not be feasible to install on existing buildings.

Increased tree canopy and green roofs helps improve evapotranspiration and slows the stormwater flow. Increased pervious pavements help improve the filtration and infiltration. Rain gardens and infiltration trenches increase the sites’ capability of retaining and absorbing water. Cisterns and
rain barrels hold stormwater and reduce the peak hour overflows. By applying GI techniques, the sites’ capability of treating and draining stormwater is improved in both alternatives. Moreover, the alternative B will further develop the alternative A, not only increasing the stormwater management but also improving the community environment significantly.

By evaluating the GI alternatives, the project demonstrates that GI can improve the stormwater management in Dayouzhuang and Saoziying. Therefore, the project attempts to promote this method to the urban villages in BMA, responding to the calling for more sustainable and more humane urban village regeneration.
7. Conclusions

This project focused on the inland flooding issues in the urban villages in the rapidly growing Beijing Metropolitan Area. Urban villages are playing an important role in easing the two conflicts happened during the process of urbanization: the conflict between the land requirement for the urban development and the outdated land policy, and the conflict between the mass rural-urban migration and inadequate affordable housing in cities. In addition, the urban villages represent the migrant culture in this particular history stage.

However, the extremely high building density, the inadequate fundamental infrastructure, and the sparse green open space, results in the environmental and social problems in urban villages. Moreover, the climate change and the concentrated rainy season result a high possibility of extreme precipitation conditions in Beijing. Combined with the inadequate sewerage and drainage infrastructure, the urban villages are threatened by the inland flooding happening in the summer monsoon season. In addition, their poor living conditions cause negative environmental impacts. Their public reputation becomes low and this leads to the issue of social injustice.

In order to solve the inland flooding issue in Beijing’s urban villages, this project proposed to use GI to improve the complicated and challenging drainage conditions. The project created a methodology that based on the understanding of the advantages and problems of urban villages, this project learns from the successful regeneration practices of urban informal settlements in the world, selects urban villages with inland flooding issues as project sites, conducts the site analysis on existing conditions, creates GI toolbox based on the site analysis, creates GI alternatives to manage the stormwater with the site conventional infrastructures, and evaluates the GI improvements in each alternative.
The project conducted the research on urban informal settlements and urban villages in China and demonstrated their importance during the process of urbanization. The project also compared the regeneration projects of urban informal settlements in Mumbai, Sao Paulo, and Beijing. From the precedent studies the project learned to treat the regeneration of urban informal settlements as a part of city regeneration by using various GI techniques to improve both the urban hydrology and living environment.

The project selected two adjacent urban villages, Dayouzhuang and Saoziying, as the project sites, which are located in an urban-rural transit area and an important water resource area in Beijing. The project analyzed the stormwater drainage conditions and problems in the sites as well as the land use, green space, building conditions, and street network. From the analysis, the project found out the challenges and opportunities of applying GI in the urban villages. The sites have limited space and many human activities, which makes it hard to find a place for installing GI. In addition, the stormwater in the sites is contaminated by pollutants from vehicles and unorganized restaurants, as well as the water flow is concentrated in the valley streets in the urban villages, which make GI implementation even harder. Fortunately, there are many buildings with stable structure in the urban villages, which provides a suitable condition for green roofs. Also, the urban villages have an existing culture of gardening, which indicates a potential community support for GI implementations, especially for community gardens.

Therefore, the project created a GI toolbox focus on improving the percentage of green roofs and pervious pavements in the sites. The toolbox also selected rain gardens, infiltration trenches, rain barrels, and cisterns to improve the sites’ capability of retaining and storing water. Also, the GI toolbox attempted to increase the percentage of green spaces and reinforce people’s outdoor activities in the urban villages.
Moreover, based on the analysis, the project created a stormwater management system. The system was composed of proposed major stormwater management veins and minor stormwater management veins. The major veins were designed to ease the flooding threat in the valley streets, support the commercial and outdoor activities, and demonstrate the GI benefits. The minor veins were designed to extend the GI implementations through the entire urban villages and increase the percentage of pervious pavements. According to the stormwater management system, two GI alternatives were created. The alternative A was a short-term and low-level intervention plan. It limited the building removal up to 2%, mainly developing the major veins and increasing the percentage of green roofs and pervious pavements. The alternative B focused on the long-term vision. It allowed the building removal up to 15%, further developing the major veins in the alternative A, and extending the minor veins by creating pocket parks. Also, the alternative B formed the commercial and residential centers in the urban villages.

The project evaluated the two alternatives, and found out that GI implementations would improve the sites’ capability of retaining and infiltrating stormwater within a relatively low-level intervention, and therefore reduce the peak hour flow and mitigate the inland flooding problem. Both of the alternatives increased the area of canopy cover, pervious pavements, and green roofs, as well as increased the usage of rain barrels, cisterns, rain gardens, and infiltration trenches. The limited space restrained the implementation of GI, especially pervious pavements and open spaces. In the alternative A, with 2% building removal, the area of open spaces was not increased as significantly as that in the alternative B with 15% removal. However, green roofs represented an encouraging vision by showing the possibility of installing on the buildings. In the alternative A, the percentage of green roofs reached 18.1%, and in the alternative B, it reached to 27.1%, which is nearly a 50% increase. The tree planting on the streets was also limited by the available space, but the community gardens and the front yard gardens showed a significant possibility of increasing the canopy cover.
Limited by the existing site information, the GI evaluation focused on the GI techniques that could be measured by area on the maps. If possible, a more comprehensive evaluation is needed to quantify the capacity of GI in stormwater management. Also, because of the lack of municipal pipe information on the sites, stormwater flow was estimated. In order to complete the map of stormwater flow, the project has to know the distribution of the pipes, and their diameter and underground depth. If this information was available, the quantity of the controlled stormwater could be calculated more accurately.

Improving stormwater management is only one aspect of GI’s benefits. Other benefits include climate remediation, air quality improvement, community improvement among other benefits. For example, by increasing the GI area in the urban villages, the planting area would be also significantly increased. More plants could have more photosynthesis process, which helps reduce the density of carbon dioxide and increase the density of oxygen. Also, more surface area of leaves could have more evapotranspiration, which helps cool the heated urban environment. This is very crucial in big cities such as Beijing, which has a severe problem of air pollution with PM 2.5, particulate matter whose diameter is less than 2.5 mm, and urban heat island effect. In terms of social and cultural benefits, the increased open spaces could provide more public places for people to meet, chat and play, reinforcing the social connections. Moreover, the community gardens could produce fruits and vegetable, creating economic benefits. Therefore, the image of urban villages—poor, dark and unhealthy environment—would be changed to pleased, robust and lively environment with high community identification.

In term of recommendations for future practices, the key point of GI implementation is “learning by doing”. Urban villagers are the best candidates for GI maintenance and monitor. They are the people that are most close to GI and therefore they must be sensitive to its changes. They could quickly observe if there was any GI working improperly for example by being trained to measure rainfall, maximum daily temperature – and to collect stormwater samples at locations before, and
after treatment by GI. The maintenance and monitoring keeps GI in a good condition and tracks the change of stormwater quality and quantity. Therefore, the GI could be continually adjusted and improved to match the co-changing site conditions.

Moreover, urban villagers helping GI maintenance and monitor is one of the important parts of community involvement. Another part is growing fruits and vegetables in the community gardens and front yard gardens. Urban villagers working in their own community not only produces profits, but also cultivates their sense of community. Therefore, they would be more willing to work for the community spontaneously, which saves the labor cost for the governments.

Moreover, here would recommend several GI technics as the start point of the regeneration. In the project, both of the alternatives have to build on considerably abundant budget. If the urban village regeneration started with a low budget, since the migrants who dominate urban villages belong to the low-income population, tree planting, rain barrels and traditional roof gardens would be the best three choices. They are naturally cheap, very effective, and easy to be found in China. The traditional roof gardens have had a long history in China. They are more similar to the community gardens but located on the rooftops. People have grown various fruits and vegetables on their rooftops. They are planted in a planter or a trellis instead of in the soil layer equipped on the roof. Without refreshing the entire roof, they could be much cheaper and easier.

In summary, regenerating urban villages in Beijing with GI could effectively mitigate the inland flooding problem; moreover, it helps improve the air quality, increase green spaces, raise the sense of community, and create a happier and healthier living environment for urban villagers—the migrants who are playing an important role in the urban developments.
8. Appendices

A. Proposed Stormwater Management System
B. GI Alternative A—Master Plan
C. GI Alternative B—Master Plan
9. Reference


UN-HABITAT Urban Indicator Database, 2013. [http://www.unhabitat.org/stats/]


