Environmental Adaptability Analysis of Sandaoguai in Chongqing, China for Sustainable Mountainous Vernacular Settlements

Yizhou Zhao* and Ke Liu

School of Architecture, Tsinghua University, Beijing, China

Abstract: Urbanization is unavoidable to be one of the most substantial challenges for almost all the countries/regions. Together with the rapid urbanization, China is putting more and more focus on sustainable construction regardless of urban development or rural development. Mountainous vernacular settlements evolved to adapt to the surrounding environment for an extremely long time through try & error method, and thus reflected ecological and cultural values of the past. In order to get the experience from those mountainous vernacular settlements and provide sustainable suggestions in Western China, the relationship between building forms and the surrounding environments are examined through environmental adaptability analysis. First, as a typical mountainous vernacular settlement in Chongqing, China and one of the Chinese famous historical & cultural street, Sandaoguai is introduced as the illustrative example. Second, building forms and the surrounding environments are classified based on literature review and the local situations. Third, relationships between different building forms and the various environments are investigated from the perspective of environmental adaptability analysis. Moreover, the field study could provide some hints for the analysis. Finally, sustainable suggestions are provided for the conservation and preservation of mountainous vernacular settlements.

Keywords: Environmental adaptability analysis, building form, environment, mountainous vernacular settlements, Sandaoguai

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1 INTRODUCTION

China has been witnessed as the fastest growing countries in the world since its economic reform in 1979. During the development of the economy, urbanization is considered as one of the major drivers. China’s urbanization population increases from 194.99 million in 1979 to 813.47 million in 2017. At the same time, the urbanization rate increases from 19.99% in 1979 to 58.52% in 2017 (National Bureau of Statistics of China 2018). Figure 1 shows the urbanization process in China from 2000 to 2017. It presents a straightly increasing trend in both urbanization rate and urbanization population. It should be noted that the urbanization rate (the urbanization population) is not registered urbanization rate (registered urbanization population). In fact, the registered urbanization rate is 42.35%, which is much lower than 58.52%. In March 5, 2016, Chinese Premier Keqiang Li proposed an urbanization target in the government work report: the urbanization rate and registered urbanization rate achieve 60% and 45% respectively in 2020 (Li 2016). In this regard, the urbanization will continue to be the necessary part of future development and thus a dramatic number of buildings will appear for living and working. However, current urban development tends to construct similar buildings in different cities regardless of different environmental circumstances, local cultures, existing buildings etc. It is destroying the local ecological systems & traditional culture, and thus considered to be unsustainable. Sustainable construction therefore becomes a significant challenge for China in the coming years.

Sustainable construction refers to the buildings which are environmentally responsible (Ramesh 2015; Lee and Lam 2015; Garg et al. 2016; Obia et al. 2016) and resource-efficient (Attmann 2012; Chowdhury et al. 2017) through their life cycles, including planning, design, construction, operation, renovation and demolition. Construction has significant and irreversible effects on the environment (Ofori et al. 2000), including land use, natural resource consumption etc. In order to achieve the sustainable goals, a number of green construction standards have come into effect, for example, LEED (Leadership in Energy and Environmental Design) in United States, LEED Canada, BREEAM (British Research Environmental Assessment Method) in United Kingdom, CASBEE (Comprehensive Assessment System for Building Energy Ef-
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Figure 1. Urbanization trend of China from 2000 to 2017

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Efficiency) in Japan and Green Building Rating System in Korea. In particular, China established the ESGB (Evaluation Standard of Green Building) in 2001. In 2006, the Ministry of Construction in China issued the “Evaluation Standard for Green Building” (ESGB) (GB/T 50378-2006). In addition, Chinese Green Building Evaluation Label has conducted the evaluation for several years since 2008. There are a total of 4,515 labelled projects before September, 2016. There projects include 4,246 green design projects and 269 green operation projects (China Green Building Evaluation Label 2018). In addition, Table 1 presents the distribution of labelled buildings in different provinces in China. The Western China, including Shaanxi, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Inner Mongolia, Gansu, Xinjiang, Ningxia and Tibet (colored ones), has 752 projects, accounting for 16.66% of total projects. At the same time, the area of Western China is around 671 km², which is about 70% of China. It should be noted that Hong Kong has its own green building rating system so that Western China’s sustainable construction percentage is even smaller. It’s found that (1) Western China is facing the substantial challenge of sustainable construction; (2) sustainable construction should put more focus on the existing buildings rather than the new buildings.

Most of the Western China is mountainous districts and thus their sustainable development is an integrated responsibility of urbanization. The preservation and transformation of traditional architecture in mountainous historical districts becomes an essential issue in China. In this regard, local environmental and existing buildings should be examined in detail to provide sustainable vernacular settlement solutions for those mountainous districts, especially the relationship between space forms and the environment (Sabri and Abbaspourasadolah 2014). In particular, the architecture of vernacular settlements reflects cultural values of the past. These building types and their site planning have evolved through time using trial and error methods. They were able to respond to the needs of their inhabitants, the climatic conditions, and the topography, because of the simplicity of the building processes, the techniques and the local materials employed (adobe, stone and timber). Sandaoguai, known as one of the “Chinese famous historical and cultural Streets”, has local vernacular architecture typology in the traditional style and unique environmental conditions, which makes it a typical case.

Environmental adaptability analysis provides a scientific framework to investigate the relationship between building forms and the surrounding environments. The word “adaptability” is originally derived from biology, and has been manipulated in various famous theoretical books, such as the principle of natural selection and Darwin’s fitness (Henderson 1913). In the field of urbanism and architecture, the mid-20th-century witnesses the beginning of the focus on the environmental adaptability in various directions. Lynch, as the pioneer in proposing the conception of “environmental adaptability”, elaborates systematically about the relationship between subject and object, and illustrates physical means of attaining it in urban planning (Lynch 1958). Another typical example is “Design with Nature” (McHarg 1995). This monograph takes an ecological adaptability view, and advances adaptability theory into design principles and practice standards. Moreover, many other scholars shared similar interests and thus put forward a series of concepts, such asbioclimatic design (Olgyay 1963), bioclimatism (Coch 1998), form follows climate (Correa 1969), etc. Meanwhile, to delve deeper the relationship between human, architecture and environment, one Chinese Academician, Wu Liangyong, proposed the theory titled “Science of Human Settlements”, which emphasizes the role of environmental forces and provides theory & method-
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Table 1. Distribution of labelled green buildings in China

ology to study the relationship between space, human beings and the environment (Wu 2001). At the present, there are more and more scholars and studies focus on the environmental adaptability analysis of building forms, especially building forms of vernacular settlements and architecture (Zhou 2014), and also combine with the theory framework of regionality which concerned about the space formation of architecture and cities (Shan 2010).

With the aim of sustainable development for mountainous vernacular settlements, the rest of the paper is organized as follows. Section 2 presents the methodology of this research. The classification of space forms and environment is stated in Section 3. The environmental adaptability analysis is conducted by taking Sandaoguai as an illustrative example in Section 4. Conclusive remarks are drawn in Section 5.

2 RESEARCH METHODOLOGY

In order to achieve the predefined research objectives as shown in (Figure 2), the research will be conducted according to the following steps:

1. Demonstrate the nature of a typical mountainous traditional district named Sandaoguai by field study. The author stayed in Chongqing for more than one year, collected different types of Sandaoguai and provided the key features of this mountainous vernacular settlement.

2. Clarify the classification of space forms and the environment in Sandaoguai through the site investigation and literature review. There are a number of different classifications of space forms and environment. Regarding Sandaoguai, the author chose suitable ones for further analysis.

3. Investigate the relationship between space forms and the environment by environment adaptability analysis. The measurements were conducted for more than one year to get the ventilation and humidity etc. from different samples.

3 SANDAOGUAI CASE AND ITS BUILDING FORMS AND ENVIRONMENTS

Numerical mountainous traditional districts located in the Western China. Those mountainous vernacular settlements provide extremely good examples for investigating the relationship between building forms and environments, especially from the historical perspective. These traditional buildings evolved to adapt the surrounding environments, including macroclimate and microclimate, topography and land use, culture landscape and local natural resources. In this regard, environment adaptability analysis is suitable for the study, it can lead a better understanding of the formation of the Sandaoguai settlement and its building forms. Sandaoguai, known as a “Chinese famous historical and cultural Street”, is a typical architecture typology in the traditional style to get along with its environmental conditions. In order to examine the environmental adaptability of building forms in Sandaoguai, the classification of the space form types and the environment categories are also examined.

3.1 Sandaoguai – A Typical Mountainous Vernacular Settlement

Sandaoguai located in Changshou District, Chongqing, China (as shown in Figure 3). Figure 4 shows that it is a zigzags
street, which is a market building complex beside the Yangtze River. Its construction began in the middle of the Ming Dynasty and was expanded in the Qing Dynasty and the Republic of China. There are more than 100 houses with more than 25,000 m² construction area. It is the epitome of the local history, reflecting the adaptability of environment for hundreds of years.

All the buildings are mainly constructed with Chuandou System (through type timber frame), supplemented by a beam-lifting structure, and mostly in the prototypes of Tianjing courtyard plane and Bamboo tube plane in the Ming and Qing Dynasties. The roof is a small blue tile roof (Figure 5). Figure 6 and 7 show the current vernacular settlement layout and two street facades of Sandaoguai.

3.2 Three Types of the Building Forms

Sandaoguai is characterized by its traditional architectural typology and unique environmental conditions. Due to the multi-dimension of the environment, Sandaoguai has various distinctive building forms, from macro scale to micro scale. Previous studies (Olgyay 2015; Fathy, 1986; Hawkes, 2001; Song 2013) reveals several major classifications of spatial forms, generally, the main classifications are according to different scales, including settlements, architecture and detail construction. Based on the previous studies and combine the purposes...
of this study, the building forms in Sandaoguai could be briefly divided into three levels: street form, house form, and detailed form. In this research, street form refers to the layout of the whole settlement, especially the form of the main street and the cold lanes. House form mainly focuses on different spatial prototypes and their organization. Detailed form means the detail structure of the house, such as openings, envelope materials and construction.

3.3 Three Categories of the Environments

In the field of vernacular architecture, Rudofsky (1964)) extended previous studies by identifying different types of the environment, including natural, technological, and cultural environment. Rapoport (1969)) presents a systematic summary of the formation and evolution of traditional architecture, where he sums up several elements, such as natural conditions, construction methods, technical means, and emphasizes sociocultural environment as an essential factor. Wu (2001)) divides environmental forces into two categories, natural environment and social environment, combining several sub-classifications of social environment, including culture, economy, and technology. With respect to local conditions in Sandaoguai, this paper focuses on three main categories of environment for environmental adaptability analysis: natural, socio-cultural, and economic/technological environment.

1. Natural environment is most often applied to the earth or some parts of earth. It encompasses the interaction of all living species, climate, weather and natural resources that affect human survival and economic activity.

2. Socio-cultural environment refers to the immediate physical and social setting in which people live or in which something happens or develops. It includes the culture that the individual was educated or lives in, and the people and institutions with whom they interact.

3. Economic/technological environment. Economics focuses on the behavior and interactions of economic agents and how economies work. Technologic environment means the technology employed in the specific time period.

4 ENVIRONMENTAL ADAPTABILITY ANALYSIS OF BUILDING FORMS IN SANDAOGUAI

4.1 Environmental Adaptability in Street Form

Among all the environment types, the natural environment is the primary impetus for the formation of street space in Sandaoguai due to multiple factors, including topography, climate, water, etc. One prominent natural factor is the local mountain topography. As a mountainous historical district, the distribution of street space descends along the hill from the top (the mountainside) to the bottom (the riverside) in a series of zigzags. This exactly shows the result of natural environmental adaptability in terms of the topography. A zigzags street is the adaptability result in seeking balance of living area and arable area as arable land has higher value for the local people in mountainous regions in ancient times. Also, the name of Sandaoguai in Chinese is inspired by its unique zigzagged street form where there are three distinctive corners (Figure 4). In addition, there are several other street forms that due to the mountain topography:

1. The layout of the settlement rises vertically up the mountainside, while the plan of each single house extends horizontally along the contours.

2. The houses on the street corner have the corresponding rotary layout and space (Figure 8).

3. The multi-story buildings have different entries on different height levels facing the street, which provides independent entries for individual families (Figure 9).
Equally important, another natural factor is the local climate with a relatively high temperature and humidity. To pursue comfortable living conditions, several characteristics of the street form demonstrate the adaptability of the local climate, that is:

1. The street runs down from the mountainside to the riverside, which helps the settlements draw support from the mountains to resist the heat and take advantage of the water to supply cool air (Figure 10).

2. The vertical, continuous and narrow street form (around 2.5 km long, 4m wide) improves the natural ventilation according to the basic principles of air pressure.

3. The narrow street form makes it easier for people to walk in the summer because it increases the amount and the duration of shade, as well as cooling the street (Figures 11-13). In the extremely hot period in summer, we use thermal infrared imager took the pictures of the street (shown in Figure 12), which illustrate that the maximum difference in street surface temperature can reach to 7°C with the surface temperature in the shadow (38.6°C) and the surface temperature in the sunshine (45.2°C).

4. By laying out together, there comes out the cold lane and the adjacent gables prevent houses from direct sunshine, which in some degree, decrease the interior temperatures (Figure 14).
Figure 12. Thermal infrared picture of the street in summer

Figure 13. Shadows in the main street in the noon of summer

Figure 14. The picture and Thermal infrared picture of the cold lane
4.2 Environmental Adaptability in House Form

Obviously, the socio-cultural environment acts as the vital role in the adaptability process of house form. In the past, Sandaoguai was one of the famous traditional Ba Salt Streets in Ba Shu mountainous region, which represents a walking commercial street style for salt and other retail commodities (Figure 15). Due to this socio-cultural demand, the house space turns into a certain typical form, called for “retail in front, living behind”: the rooms beside the street are usually a large interior space for retails and shops, while the living rooms are behind the retail room, or through a courtyard that behind the retail space.

Figure 15. Sandaoguai as the Ba Salt Street

Compared to the general typology of traditional architecture in the Ba Shu mountain region, the house form in Sandaoguai also has other characteristics as follows (Figure 10):

1. No porches or other semi-open spaces in front of the retail room which directly faced the street and its open most of the time.
2. The depth of the architecture is deeper since the layout needs to fit the functional requirement for mix-use of “retail in front, living behind” (Figure 16).
3. Some houses have excavated cave space for storage and additional use.
4. The basement of the architecture along the street side directly connected with the road surface, unlike the basement construction of other vernacular pillar-supported dwellings in the same region.

Figure 16. Plan for “retails in front, living behind”

At present, some people convert the retail room into a dining and living room, while other people change it to a multifunction room, like a tea house, a drawing and design studio, or an antique exhibition room, etc., which indicates the adaptability of the current socio-cultural environment.

4.3 Environment Adaptability in Detailed Form

The detailed form adapts primarily to the economic/technological environment. One obvious feature is the changing type of architectural materials. In the first generation of these traditional buildings, the majority of them were made from wood, bamboo, and mud, all of which are natural and local materials, and perfectly matching the local hot weather and traditional built technology level in Sandaoguai area. Later, with the development of economics and technology, there emerged some new buildings with bricks and concrete. At the same time, more and more residences spontaneously renewed their house by integrating new materials into the old ones (Figure 17). Recently, the young generations re-decorated their houses with waterproof, fireproof, and insulation materials, so as to achieve better quality housing station, more suitable thermal conditions and a more fashionable and modern interior style.

Figure 17. Changing types and utilities of architectural materials

Another feature shown in the water facilities demonstrates the traditional wisdom of scientific principles and mature local technologies. Every house has outside washing facilities, and the drainage system is under the two edges of the main street and goes all the way down from the mountainside to the riverside. There is also a sub-drainage system along the horizontal contours line that drains the water from the street, making it easier to keep the main street surface and architectural entries dry and clean (Figure 18).

5 CONCLUSION

In order to achieve the sustainable vernacular settlements in mountainous Western China, the research analyzed the environmental adaptability of traditional architecture by examin-
ing the building forms and the surrounding environments. It is found that (1) the street form with its unique zigzag form is mainly caused by natural environmental adaptability, especially due to the local mountain typology and local climate conditions; (2) the outcome of the house form in terms of “retails in front, living behind” is strongly correlated to the socio-culture environment, where the area is served as a salt retails street with a high reputation in the past; and (3) the adaptability of detailed form in architectural material utility and water facility construction ties close with the technology/economic environment, integrating the traditional wisdom and modern applications. In the case of Sandaoguai, it shows that each type of the building form is dominated by one type of environment. This adaptability characteristic of the building forms in Sandaoguai reveals a unique identity about the formation of Sandaoguai by demonstrating the relationships between the different types of building forms and the distinct categories of environments. As a whole, the results of the adaptability relationship in Sandaoguai illustrate meaningful value both for research and practice, and could provide reasonable thinking and reliable design references in the pursuit of future sustainable development for historical preservation and modern transformation.

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Figure 18. Water facilities and drainage system

ACKNOWLEDGEMENT

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