The Influence of Sustainable Concept of Chinese Traditional Dwellings on the Design and Evaluation of Green Buildings

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***Abstract*—The survival and development of human beings are profoundly affected by global climate change and environmental degradation. Therefore, building a low-carbon society has become a global common goal. Buildings need to consume a lot of natural resources and energy during the process of construction and operation; this is one of the main sources of greenhouse gas emissions. The transformation of the urban development model from extensive to refined would be inevitably caused if ecological development can be achieved; this is the goal of green buildings. The harmonious coexistence of man and nature is advocated in Chinese traditional culture. After thousands of years of development, Chinese traditional houses that are represented by the pit courtyard embody the characteristics of historical rationality and sustainable development, and would inevitably have a lasting influence on the theory of green building.**

***Index Terms*—Chinese traditional dwellings, pit courtyard, sustainable development, green building**

I. Introduction

The rapid development of industrialization and urbanization in the world has led to huge energy consumption, environmental pollution, climate warming, and other global problems. In China, building demand and comfort requirements increase simultaneously with the continuous growth of population and the continuous improvement of people's material living conditions, and the total building energy consumption increases year by year. In 2016, China's total building area was 63.5 billion m2; the total energy consumption was 899 million tons of standard coal, accounting for 20.6% of the country's total energy consumption; the total building carbon emissions was 1.96 billion tons of CO_2, accounting for 19.4% of the country's total energy carbon emissions [1]. Therefore, the field of the building should re-understand the relationship among nature, building, and human beings from a new and scientific perspective.

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II. Concept and Development of Green Buildings

Green building is a method to realize a sustainable idea during the process of urban construction. It needs a clear design idea, concrete technical support, and an operable evaluation system. The concept of green building focus on different points in different institutions and different angles [2-3]. Wikipedia describes green buildings as practical activities aimed at improving the efficiency of the use of buildings in terms of land, energy, water, and materials while reducing the negative impact of buildings on people's health and the surrounding environment through more careful and comprehensive consideration at all phases of the life cycle, including design, construction, use, maintenance, and demolition.

In 1969, American architect Paolo Soleri proposed the concept of Arcology and expounded it in his book *Arcology: the city in the image of man* [4]. American architect Lan McHarg pointed out in his book of *Design with Nature* that Arcology is a theory and method of architectural planning and design based on ecological theory and man, building, nature, and society should develop harmoniously, exploring the construction and design methods of Arcology.

In 1976, Dr. Anton Schneider founded the Society for Architectural Biology and Ecology in former West Germany, which advocated the health and ecological benefits of moderate architectural art. Besides, the use of natural building materials, natural ventilation, natural lighting and solar heating of ecological buildings was explored.

In 1987, the report "Our Common Future" was released on the 8th World Commission on Environment and Development that was held in Tokyo, Japan. The concept of "sustainable development" was proposed for the first time and changed the concept of "purely considering environmental protection" in the past; it led to "combining environmental protection with human development" and realized the important leap of human thinking on the environment and development.

In 1990, BREEAM, the green building evaluation system of the British Architectural Research Institute,

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was published; meanwhile, a scientific green building design and evaluation system were established for the first time in the world. In 1991, Brenda Weir and Robert Weir published Green Building: Designing for Sustainable Development, which first proposed the definition of "green building" [5]. "Green building" will be climate, environment, energy, and other elements of the overall consideration of architectural design rather than just a single starting point for people's thermal comfort needs. Combined with the design of climatic conditions, recycling of resources, and so on, the green building system and the overall design methods such as energy-saving design make the green building design become systematic and easy to operate instead of just staying in the concept and technical level.

In 1992, the concept of "green building" was first clearly put forward at the United Nations Conference on Environment and Development held in Rio de Janeiro, Brazil [4].

In 1994, the US Green Building Association (USGBC) drafted a green building grading evaluation system named Leadership in Energy and Environmental Design (LEED) [6]. In August 1998, the Pilot Program of LEED version 1.0 was officially launched; besides, LEED was gradually extended to the whole world with the commercial operation mode. It was becoming the most well-known green building evaluation system.

Up to now, the problems of green buildings have developed from the resources and environment of the present generation to the economic, social, and environmental aspects of future generations after more than 50 years of development. Therefore, the connotation of green building has been developed from the comfort of the human body and building energy consumption to the safety, service, health, environment, resources, and management related to people's lives.

III. Sustainable Concept of Traditional Chinese Dwellings

The concept of sustainable development of traditional Chinese dwellings is that people in various regions are speaking according to their own lifestyle, production needs, customary beliefs, and aesthetic concepts after thousands of years of continuous improvement and development; they combine local natural conditions and materials and adapt to local conditions Design and construction of residential buildings. Respecting the environment, combining climate, using local materials, and maximizing the harmonious coexistence of man and nature illustrate sustainability.

The Chinese people have always revered nature; the harmonious coexistence of man and nature have been always advocated in the concepts of "harmony between man and nature" and "Taoism following nature" in China's long-standing traditional culture. The Chinese ancients emphasized "moderation" in the building; besides, they often understood "earth" as the unity of natural, social, and economic conditions, or the trinity of time, place, man, and nature in the study of human geography.

China has a vast territory and a large number of nationalities. There are significant differences in climate and culture among different regions. Therefore, Chinese dwellings have their own characteristics. Mr. Qi Kang [7] believed that “each city and region has its own characteristics based on the social needs, natural environment, climate, topography and geology, local construction technology, ethnic customs, history, and culture. The characteristic has its own evolution process; local architecture is related to the social economy, history and culture, science and technology, local building materials, construction-related engineering measures, and so on.”

Chinese traditional dwellings are a comprehensive reflection of the natural environment, including climatic characteristics, building materials, production methods, beliefs, customs, and other social conditions, as well as construction methods and economic capacity and other factors. Moreover, they are also the embodiment of the best balance strategy. After thousands of years of accumulation, China's traditional residential reflects the historical rationality and sustainable development of the characteristics.

IV. Cave-dwelling Culture Bred by Loess Areas——Pit Courtyard

In the loess areas of Henan, Shanxi, Shaanxi, and Gansu provinces in China, people dig deep holes in flat hilly land with square or rectangular planes and dig caves along the surface of the holes that are called pit kilns or patio kilns in order to adapt to the geological, topographic, climatic, and economic conditions. The cave is connected to the ground by various steps. The tunnels are dug to connect with the outside if there is a natural cliff nearby. A large pit courtyard has two or more pits connected and can accommodate 20 or 30 households [8].

Figure 1. Earliest aerial photograph of the Shaanxian pit courtyard (shot by German pilot WulfDiether Graf Castell Ludenhausen, 1933-1936)

My grandfather and father grew up in a pit courtyard. The pit courtyard has a history of 1500-2000 years and belongs to the unique residential form of the Loess Plateau. Besides, it is the physical witness of the evolution of the history of human "cave dwelling". This peculiar form of dwelling is unique in China and even in the world. As the "underground pit courtyard" in northern China, the pit courtyard is still inhabited by people; it is best preserved in Sanmenxia, Henan Province, where

there are still more than 100 underground villages and nearly 10,000 pit courtyards. The earliest pit courtyard has a history of more than 200 years and has been inhabited for six generations.

The pit courtyard is located at the edge of the Loess Plateau, where the climate here is dry, with less rain and thick soil layers because of its geographical location. The local loess has good integrity, stability, thermal insulation, and moderate plasticity, with the functions of anti-compression and anti-seismic; it creates unique conditions for excavating the pit courtyard. Moreover, the local residents created this form of dwelling because these places are short of stone and wood.

The structure of the pit courtyard is to a rectangular or square pit with a depth of 6-7 meters and a length of 12-15 meters on flat ground as a pit courtyard, and then dig 8-12 holes cave dwellings in the four walls of the pit. The cave dwelling is about 3 meters high, 8-12 meters deep, and 4 meters wide. The walls of the cave dwelling are vertical below 2 meters and round arches from above 2 meters to the top. One of the holes is chiseled into a slope, forming a stepped arc-shaped tunnel leading to the ground, which is the entrance to the pit courtyard [9]. The cave dwellings of a pit courtyard are dug out year after year according to the increase in population or the arrangement of leisure time rather than digging out overnight. Usually, a family lives in a kiln, or parents and children live in the same kiln. The combination of pit courtyards maintains the pattern of traditional pit courtyards in the north, forming a comfortable underground pit courtyard with kitchens and grain storage warehouses, drinking and seepage wells, and sheds for raising livestock. Pit courtyard division, traffic relations between the upper and lower levels, lighting, ventilation, and drainage are very clever treatment methods for using the lot.

Figure 2. One family, one pit courtyard

The drainage and seepage control of the pit courtyard is the most important problem to be solved in the building structure because the pit courtyard is located below the surface of the earth; besides, the structure form of the pit courtyard is mostly generated from it. The outside elevation of the cave is called the kiln face. In the pit courtyard, the kiln face is covered with mud except for the doors and windows that are often surrounded by green bricks; the base of the kiln face is often covered with green bricks. The ground in the pit courtyard is paved with green bricks along the periphery; the centre of the pit courtyard is formed by digging down about 30cm from the pit courtyard edge about 2m away. A water puddle with a depth of 4~6m and a diameter of about 1m is dug at the declination angle. The puddle is mainly used for storing rainwater and sewage, with the bottom covered with a layer of slag and the top covered with bluestone slab. An inflection kiln was dug at one side of the door-hole kiln; then, a well with a depth of 20-30 meters and a diameter of 1 meter was dug; finally, an axle roller was added to solve the draught problem of human and livestock.

Figure 3. Water well

Besides, a circle of green brick and green tile eaves should be built around the pit courtyard and the ground to drain rainwater and protect the pit courtyard walls from rainwater erosion. A 0.5-metre-high parapet on the eaves would be built; a parapet around the passageway to the bottom of the pit would be also established. The walls are designed to prevent rainwater from pouring into the pit courtyard, prevent people or children from falling into the pit courtyard by accidents when moving on the ground, and provide architectural decoration to make the whole pit courtyard look beautiful and harmonious.

Figure 4. Crossing the mountain stove. It consists of a row of stoves connected in series with 7-8 stove eyes. The firewood is burned at one end of the stove and the heat passes through the hearth to each stove.

A deep pit that is surrounded by cave dwellings allows the people to form not only such a magical dwelling but also a scene of the whole village that "trees can be seen in the distance, close enough to hear, but no one to see". The pit courtyard has the following characteristics.

A. Constant Temperature

The sealing property is good, the sun cannot penetrate in summer, and there is a very good cold-proof gas in winter because there is a very thick soil layer between the cave and the outside world. Besides, the winter basically

does not need special heating equipment as the cave has a Kang that can heat the indoor.

B. Environmental Protection

The construction of cave dwellings is entirely natural and with no generation of construction waste. The interior is not decorated with modern materials and has no effect on the ambient air.

C. Fire Protection

The building elements are largely free of wood and flammable new materials; the earthen gables are effective in stopping the fire from tipping in.

D. Low Noise

Cave dwellings are the favorite residential places for the elderly because thick soil can effectively block the noise and cave dwellings are generally built far from the downtown area.

E. Low Cost

The cave dwellings are extremely cheap and only need a good terrain for building, with no high-tech materials and high-tech technology.

F. Save Land

Cave dwellings are usually built on the edge of cliffs and ditches, saving a lot of land for farming. These buildings are ideal for the once impoverished mountaineers though poorly ventilated and dimly lit.

As an ancient and magical style of dwellings, the pit courtyard contains a rich culture, history, and science. It is the crystallization of ancient working people's wisdom, reflecting people's religious beliefs, social strength, economic development level in a certain social and historical phase. It is unique in the cave dwelling environment, recording more social and historical development track and information. In the early 20th century, GermanBernardRudofsky's Architecture Without Architects was the book first introducing the world to Chinese cave dwellings. The cave dwellings are described as "bold creation, refined technique, abstract language, and rigorous modelling". There is no doubt that the pit courtyard is a miracle in the history of Chinese buildings and records the history of the local residents. In 2011, the "Construction Techniques of the Pit courtyard" was included in the third batch of national intangible cultural heritage list.

V. Embodiment of Sustainable Concept in the Green Building Evaluation System

The concept of sustainability is fully interpreted through traditional Chinese dwelling houses represented by ground pit courtyards. The green building design with sustainable concepts demonstrates the reduction of the impact on resources and the environment, the creation of a healthy and comfortable living environment, and the integration with the surrounding natural environment.

The rationality of sunshine and sunshade facilities and good thermal design of maintenance structure are ensured by the specific manifestations. Buildings can perform reasonable ventilation, make full use of renewable resources, effectively treat sewage and rainwater, achieve reasonable application, select the best green building materials, build a comfortable indoor thermal and sound environment, and improve air quality.

Characteristics of the sustainable idea in the green building evaluation system:

A. Practicality

As a component of the environment, the building can protect and improve the ecological function of the site only by effectively integrating into the local context and responding to the local environment. Therefore, each project is located in a different climate background and site environment, constituting its specific design context; besides, the surrounding environment fit the project must also be unique.

B. Inclusiveness

The inclusiveness of building is reflected in the protection of natural environments such as topography, geomorphology, natural landscape, and water surface, reducing the ecological impact of building on the surrounding environment and increasing the opportunities for people to get close to nature. The inclusiveness of building is also reflected in the rationalization of the exchange of architectural and environmental resources, the reduction of resource demand, the optimal use of resources, the rational use of recyclable and renewable resources in architectural design and construction, and the selection of building materials. In this way, the goals of reducing energy consumption and environmental pollution can be achieved.

C. Symbiosis

The symbiosis of the building consists of three levels, including nature, local context, and the social economy. As a famous Japanese architect, KISHO KUROKAWA combined Japanese traditional culture with Western culture, proposed the symbiosis thought in the field of architectural design and advocated the integration of culture, history, technology, nature, and society into the building. Symbiosis takes architecture as a symbol to express humanistic feelings and show local customs combining history with new architecture and architecture with local culture; finally, it realized people's sense of identity and belonging to local culture. Humans can respect nature, blend in with nature, and be harmonious and reciprocal with nature through the symbiosis of architecture and nature.

D. Diversity

Architectural diversity is the organic combination of different architectural functional spaces, showing the mixing, variability, and diversity of spatial functions. Humans should strengthen the continuity of building and external space, promote the mutual penetration of privacy and publicity, provide interactive space for the people, introduce natural light and wind into the building itself, and increase the overall vitality of the building.

VI. Conclusions

Green building is the result of introducing the idea of sustainable development into the field of the building; it has become the dominant trend of a contemporary building. After years of development, the concept of green building is constantly expanding. However, the idea of sustainable development is always the theoretical basis of green building. The traditional idea still has its survival soil no matter how advanced modern technology is. How to combine the two forms should be the key to the future study of green buildings.

The ground pit courtyard has characteristics such as low cost, constant temperature, environmental protection, fire protection, low noise, and land saving. The sustainable concept of respecting the environment, adapting to local conditions, and achieving the harmonious coexistence of man and nature has been fully demonstrated through the traditional Chinese dwelling houses represented by the ground pit courtyard. It can be known through the analysis of the sustainable concept of Chinese traditional houses that green building is not only a way of life but also a concept. It covers all types of buildings, including residential, production, living and public activity spaces instead of necessarily referring to any particular type of building. From the perspective of a single green building, its green connotation is a series such as culture, ecology, and environmental protection. Green buildings should respect the nature and different countries and regions for the design of the green building; it should be in line with the local climate and natural conditions of the standard. Some measures such as green roofs of buildings are not suitable for all places. In dry and rainy areas, green roofs are more expensive to maintain; therefore, other energy-saving measures that are more suitable for local ecological conditions are required.

The development of green building is not only a significant strategic transformation to conform to the transformation of the world economic growth mode but also an inevitable part of the establishment of an innovative country, as well as the needs of the people's livelihood; it is increasingly illustrating more and more vigorous vitality and has a very broad development prospect. Therefore, the development of the green building is the inevitable choice of building a resource-saving and environment-friendly society in the world.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Weijie Hua and Tiejun Zhou concuted the research; Jiani Bai Summarized the literature; Weijie Hua wrote the paper; all authors had approved the final version.

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