



# Landscape Design of Urban Residential Communities Toward Carbon Neutrality Goals: A Case Study of Taigu District, Jinzhong City, Shanxi Province, China

Lingling Xia

Jinzhong College of Information, Shanxi, China

## ABSTRACT

As the climate crisis intensifies, achieving carbon neutrality has become a global consensus. Urban residential communities constitute a vital component of cities. The carbon sequestration function of residential community green space systems plays a significant role in reducing urban CO<sub>2</sub> levels. By combining a literature review and field investigation, this paper focuses on urban residential communities in Taigu District, Jinzhong City, Shanxi Province, China. These communities are categorized into three types based on factors such as green space area, plant cultivation and growth, and design. The analysis identifies negative impacts on carbon sequestration efficiency in terms of spatial layout, green landscape design, plant growth and maintenance, and plant configuration. A design approach integrating "vertical (roof-to-ground) and horizontal (planar) dimensions" and "ecology-technology-human participation" is proposed. This aims to achieve carbon sequestration increments across different community types, thereby reducing the concentration of carbon dioxide in the air. At the same time, landscape quality and residents' experience are also taken into account. This strategy provides a reference design methodology for areas with scarce green space resources and high carbon dioxide emissions.

## KEYWORDS

Carbon Neutrality; Carbon Sequestration; Residential Communities; Urban Green Spaces; Landscape Design.

## 1. INTRODUCTION

Cities, as main sources of carbon dioxide emissions [1], exacerbated global warming and posed severe climate challenges. In 2018, the Intergovernmental Panel on Climate Change---an independent organization established by the World Meteorological Organization and the United Nations Environment Programme---defined carbon neutrality as "When the carbon dioxide generated globally over a given period is offset through comprehensive measures---such as energy conservation and emission reduction, carbon capture and storage, artificial and natural carbon sinks, carbon taxes, and emission quotas---the result is net zero emissions, thereby achieving carbon neutrality [2]." Different countries have planned different timelines for achieving the carbon neutrality goal: Germany expects to achieve it in 2045; Countries include the United States, the United Kingdom, Japan, South Korea aim for 2050, and China commits to 2060 [3]. With human activities and urban expansion, more and more green spaces are disappearing. Green spaces are important carriers of carbon absorption and carbon sequestration, and are key places to maintain ecological diversity. Green spaces (such as forests and parks) can effectively regulate temperature, improve the heat island effect, and protect ecological diversity [4]. Consequently, Carbon sequestration---a vital pathway to carbon neutrality--has received widespread research attention.

As a vital component of cities, urban residential communities not only serve as essential living spaces that shape residents' quality of life, but also exert a crucial influence on urban ecosystems and are closely linked to carbon emissions. However, at present, practical research on landscape design for carbon neutrality in residential communities remains limited. This paper conducts field investigation and literature research review focusing on residential communities in Taigu District, Jinzhong City, Shanxi Province, China, to propose landscape design strategies that reduce carbon dioxide and advance carbon neutrality. Section 2 outlines research methods and subjects. Section 3 reviews theoretical foundations and case studies. Section 4 analyzes policy contexts, current situations, and existing problems. Section 5 presents design strategies based on the investigation and analysis. The conclusion summarizes limitations and core research points.

## **2. METHODS**

This paper mainly uses literature review and field investigation methods for research and investigation. The literature review approach is widely utilized across various research domains. This paper will use the Web of Science database to retrieve core literature in the fields of carbon neutrality, carbon sequestration, urban green space, and landscape design to obtain and analyze the latest research theories, findings, and case studies. Regarding the field investigation method, residential communities in Taigu District, Jinzhong City, Shanxi Province, China, were first selected as sample sites; researchers resided locally to conduct in-depth investigations. Second, the current conditions of different communities were analyzed. Third, plant configurations, green space morphology and sizes were surveyed with detailed notes taken. Fourth, researchers engaged in local daily life, conducted interviews, collected relevant data, and verified information accuracy.

This paper selected Taigu District, Jinzhong City, Shanxi Province, China, as the research site. On one hand, Taigu is located in Shanxi, a traditional coal-dependent province; on the other hand, the urban green coverage in Taigu District is notably lower compared to other communities in Shanxi province, especially in residential communities, thus urgently requiring efficient "net-zero emission" strategy. This approach enables more targeted and in-depth development of effective landscape design strategies for carbon-neutral urban residential communities, advancing toward carbon neutrality goals and mitigating climate crisis.

## **3. LITERATURE REVIEW**

### **3.1. Theoretical Foundations**

#### **3.1.1. Carbon Neutrality**

"Carbon neutrality" does not mean that countries, regions, organizations, or individuals release or produce no carbon dioxide. Instead, it is necessary to offset the carbon dioxide in the air through the above-mentioned carbon sequestration, carbon taxes and other means or methods to achieve a relative "net zero emission" balance. Broadly speaking, carbon neutrality can refer to greenhouse gas neutrality, net-zero CO<sub>2</sub> emissions, or net-zero greenhouse gas emissions. Narrowly defined, however, it applies only to achieving neutrality for carbon dioxide among all greenhouse gases [5]. This paper mainly focuses on the narrow sense.

#### **3.1.2. Carbon Sequestration**

Research on carbon sequestration began in 1977. It typically refers to capturing carbon dioxide from the air through technology or organisms, plants, soil, etc., and storing it in carbon pools (carbon pools are divided into atmospheric carbon pools, oceanic carbon pools, and terrestrial ecosystem carbon pools). For example, soil microorganisms and plant rhizosphere can synergistically promote t soil

carbon capture [6]. The carbon sequestration benefit of deciduous trees is much higher than that of shrubs [7]. Plant stems have the highest carbon deposition, while plant roots have the lowest [8].

### 3.1.3. Urban Green Spaces

The meaning and interpretation of Urban Green Spaces vary across different countries, research contexts and disciplines [9]. Scholars have also conducted relevant research on how to define urban green space, proposing that urban green space usually refers to urban space or artificially constructed ecological areas composed of natural elements through human intervention, such as basic vegetation (such as lawns, shrubs and trees), and soil layers, etc. [10]. In the field of carbon sequestration and carbon fixation research, urban vegetation has received increasing attention [11-12]. Urban green spaces, as important carbon sinks, can sequester large amounts of carbon dioxide through plant photosynthesis and thus play a key role in achieving carbon balance [13].

## 3.2. Related Cases

Green roofs using sewage-sludge mixed matrix (sewage sludge and local natural soil volume ratio 1:1) can effectively improve carbon sequestration [14]. Rooftops in Mashhad, Iran, covered with sedum species and rosemary can sequester a large amount of carbon [15]. Researchers pointed out that in Guangzhou, vertical greening delivers optimal carbon reduction in Guangzhou [16]. Combining carbon capture and storage technology with 3D concrete printing can substantially reduce carbon footprints [17]. Adding potassium to biochar can effectively improve carbon sequestration efficiency [18].

## 4. FIELD INVESTIGATION AND ANALYSIS

### 4.1. Policy Background

In China, the official carbon offset label emerged in 2008. In 2009, ecological and climate-related work received focused attention, with relevant meetings proposing a 40%-25% reduction in carbon dioxide emissions by 2020 compared to 2005. On September 22, 2020, China announced at the 75th UN General Assembly its commitment to peak emissions before 2030 and achieve carbon neutrality by 2060. In Shanxi, relevant organizations have established a carbon emission accounting system, especially for key industries such as building materials, urban and rural construction, transportation, etc.; monitor carbon emissions and establish an early warning mechanism; and incorporated greenhouse gas emission control indicators into environmental impact assessments.

### 4.2. Current Situation Analysis

Through field investigation of residential communities in Taigu District, Jinzhong City, Shanxi Province, three community types were identified based on green space coverage, plant growth, and design. The first category is no green space: primarily older residential communities and ancient city dwellings featuring only buildings and hard-paved surfaces to meet the most basic living needs. The second category is limited green spaces: minimal vegetation dominated by isolated trees or simple linear green belts combining sparse trees with single shrub species. There is no complex or diverse landscape design. This type of residential community includes some older communities. The third category is moderate green spaces: most of this type of residential communities that have been planned and constructed in recent years with intentional plant combinations and basic landscape planning. However, there are still problems such as stunted tree growth, sparse foliage, insufficient plant layering, and low planting density.

### **4.3. Identified Problems**

Under carbon neutrality objectives, through the analysis of the current situation of residential communities in Taigu District, Jinzhong City, the following problems were identified. First, from a spatial perspective, some communities lack any green space: courtyards are limited or situated adjacent to the street, or have been designated as parking areas, making greening or retrofitting difficult. Second, regarding landscape design, site planning is often unreasonable; some vacant areas are underutilized yet still encroach on potential green space. Design approaches tend to be monotonous, employ unsustainable methods, or use high-carbon-emission materials (for example, extensive concrete paving). Third, in terms of plant growth, many plants exhibit poor growth and maintenance, leading to sparse foliage, reduced photosynthesis, and lower carbon sequestration efficiency; a few plants even wither. Frequent improper pruning of lawns, trees, and shrubs results in stunted, weak specimens. Fourth, plant selection and configuration are overly uniform: vegetation layers are limited and many trees are evergreen, which hinders synergistic carbon sequestration benefits. Fifth, local residents generally have limited understanding of carbon neutrality and show weak willingness to participate in related efforts. Finally, economically, high costs and budget constraints make it difficult for residential complexes to achieve high green coverage rates.

## **5. DESIGN STRATEGIES**

In order to enhance carbon sequestration efficiency in residential communities in Taigu District and promote the goal of carbon neutrality, the green landscape of residential communities can be transformed or constructed based on the "ecology-technology-human participation" approach. This also should be combined with the "vertical-horizontal" design method. Vertical refers to designing from the building roof down to ground level, such as focusing on roof gardens, vertical greening, and ground lawns. Horizontal refers to horizontal design of the site, such as focusing on plant configuration, plant species, green space area, and ecological diversity, etc.

### **5.1. Residential Community Green Spaces**

Due to space limitations in some communities where adding green space in courtyards is impossible, the vertical design method can be adopted to increase green space, thereby expanding vegetation area and enhancing carbon sequestration capacity. First, roof gardens can be added to load-bearing roofs, and local sedum plants can be planted to reduce the pressure on ground-level green spaces [19]. Second, ecological green walls, that is vertical greening can be employed. For example, use *parthenocissus tricuspidata*, which is widely distributed in Shanxi. In terms of horizontal design, plan rational pedestrian and vehicle circulation, strive to maximize green area, reduce hard paving, and utilize corner and edge spaces. For communities with limited courtyard space, construct strip-shaped green belts or tree pits to maximize plant planting, using high carbon sequestration plants such as native Shanxi broad-leaved tree species.

### **5.2. Plant Configuration**

In terms of plant configuration, a multi-layered planting combination method of grassland-shrubs-small trees-large trees is adopted to give full play to the carbon sequestration potential of different plant layers. Lawns, shrubs and trees can also store a large amount of carbon dioxide in the atmosphere, but this is often overlooked. In addition, native plants need to be used to maintain local plant diversity. For example, trees can include fast-growing broad-leaved species like poplar, willow, locust, and paulownia; the carbon dioxide absorption capacity of this type of tree is higher than that of coniferous species [20]. Seasonal changes and ornamental value should also be considered.

### **5.3. Low-Carbon Building Materials**

Adopting the sponge city design method, using permeable paving bricks, ecological grass-planting bricks, etc., is conducive to stormwater management, mitigating the heat island effect, reducing building energy consumption, and promoting low-carbon urban development. In addition, using sustainable landscape building materials, such as hemp lime, which has a good net carbon dioxide emission profile [21]. Sustainable building materials like air lime can also be used to effectively reduce carbon dioxide [22].

### **5.4. Integrating Modern Technology**

As technology advances, science and technology has become an important way to improve carbon sequestration efficiency. Residential communities can install relevant equipment to monitor, manage, and predict plant carbon sequestration efficiency and carbon dioxide emissions in real time through technology. Smart technology can also be used to upload monitoring or prediction data and carbon neutrality-related knowledge to mobile applications, enabling visualization. This not only educates people about carbon neutrality but also allows them to participate (for example, doing related tasks, completing small games, or receiving guidance for planting high carbon sequestration plants on balconies or roofs).

### **5.5. Universal Participation in Carbon Neutrality**

In advancing carbon neutrality, participation is needed not only from decision-makers and designers but also from active resident involvement. Communities should conduct lectures on carbon neutrality and ecology, increase publicity efforts, and raise residents' low-carbon awareness. Open channels for resident evaluations or suggestions to promote joint maintenance of community green spaces. It is also necessary to enhance the skills of landscaping staff to improve plant maintenance and pruning.

## **6. CONCLUSIONS**

This paper employs literature review and field investigation methods. It also analyzes residential communities in Taigu District, Jinzhong City, Shanxi Province, China. It proposes landscape design strategies for urban residential communities targeting carbon neutrality. The paper clarifies relevant concepts, analyzes case studies, and examines the policy framework at the research site. Based on the current state of residential communities, they are categorized into three types. Issues identified include insufficient space for green space development; monotonous, irrational, and unsustainable designs; inadequate plant health maintenance; low diversity in plant configuration; weak resident awareness of carbon neutrality; and constraints on green space construction due to investment and maintenance costs.

Finally, a comprehensive design strategy integrating "ecology-technology-human participation" and "vertical-horizontal dimensions" is proposed, offering new ideas for landscape design in urban residential communities under carbon neutrality goals. At the ecological level, the core approach involves multi-layered combinations of grass-shrub-tree planting, selecting native, high carbon sequestration efficiency, and fast-growing plants. At the technological level, advanced solutions such as smart monitoring and digital management of plants or green spaces are introduced, with feedback provided to residents via applications or platforms. For human participation, methods like community engagement, education, awareness campaigns, and incentive tasks are used to enhance residents' low-carbon awareness and participation enthusiasm, alongside strengthened training for landscaping staff. Regarding vertical design, make full use of vertical space to achieve the maximum degree of greening in a limited space. Pay attention to the energy conservation and emission reduction of buildings and their combination with vegetation to achieve sustainable and low-carbon life. For horizontal design,

optimize the pedestrian and vehicle movement lines and spatial layout, improve space utilization, rationalize plant configuration, and enhance green space continuity.

However, the study is mainly based on short-term investigation of different residential communities in Taigu District, Jinzhong City, Shanxi Province, and thus has certain limitations and lacks long-term monitoring data such as carbon flux. In the future, long-term investigation and data monitoring can be carried out in urban residential communities across different climate regions, enabling comparative analysis to validate the design strategies.

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