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Study on Fracture Delay of High-Strength Bolts in Road Bridge Maintenance

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Abstract: In the maintenance work of highway and bridge engineering structures, the fracture delay of high-strength bolts is a content that needs to be focused on and researched. Based on this, the paper analyzes the fracture delay of high-strength bolts in highway bridge maintenance, including an overview of the fundamental research on fracture delay and related specific studies. It is hoped that this study can provide scientific reference for the reasonable maintenance of high-strength bolts, so as to ensure the overall maintenance effect of highway bridge projects.

Keywords: Highway bridge engineering; Bridge maintenance; High-strength bolts; Fracture delay; Maintenance recommendations

Online publication: September 11, 2024

1. Introduction

For the high-strength bolts used for connecting and fixing in highway and bridge engineering, the scientific research of its fracture delay is crucial in the specific maintenance work. Therefore, we should first fully understand the basic situation of this research, including its basic research background, the necessity of the research and the main research content. Then based on this, in-depth research is conducted on the high-strength bolt fracture delay in the maintenance of highway bridges, focusing on the fracture delay mechanism, non-destructive testing technology for delayed cracks, the current state of fracture delay, research conclusions, high-strength bolts maintenance recommendations, and so on. This approach allows for scientific analysis of fracture delay, providing scientific reference for the maintenance of high-strength bolts in highway bridges.

2. Introduction to the study of high-strength bolt fracture delay in road bridge maintenance

2.1. Basic research background

In modern steel bridge engineering, high-strength bolt connection is one of the most commonly used connection methods. Since high-strength bolts have many advantages such as not easy to loosen under dynamic loading conditions, fatigue resistance, removable and replaceable, good stress performance and simple construction, they have been widely used in modern steel structure bridge engineering. However, in the practical application of highway bridge engineering, with the prolongation of its continuous operation time, high-strength bolts will also have certain damages, including loosening and falling, and ordinary maintenance is usually difficult to obtain satisfactory results. For example, Japan's Fukushima Prefecture Mishima Bridge was built in 1975, and the high-strength bolts began to fall in 1987. Despite key inspections and replacements of the damaged bolts by the maintenance unit, such incidents continued to occur. Through the practical application of highway bridge engineering and the summary of its operation and maintenance work, it was found that high-strength bolt breakage exhibits uncertainty and suddenness. The specific influencing factors and forms of failure also show various characteristics. Currently, there is no systematic research on this issue, either domestically or internationally, and no conclusive findings on the law governing delayed fracture of high-strength bolts [1].

2.2. The necessity of research

Due to the high-strength bolt damage in highway bridge structure is difficult to be solved by ordinary maintenance methods, coupled with the connection of steel structure bridge and its fixing effect is mainly determined by the high-strength bolt, so it is necessary for us to carry out an in-depth study on the delayed fracture of the high-strength bolt, so that we can find out the main mechanism of the delayed fracture and its reasons, and to provide scientific references for the subsequent maintenance work.

2.3. Main research content

In this study of high-strength bolt fracture delay in highway bridge engineering, the main research content includes the following aspects.

(1) Data collection: Mastering the delayed fracture cases of high-strength bolts of steel bridges in the current stage of highway bridge engineering at home and abroad.

(2) On-site research: On high-strength bolt fracture and shedding in the operation of highway bridge projects, including the environment where the bridge is located, the operation time, high-strength bolt type, the number of high-strength bolts broken, high-strength bolts broken parts, and management and maintenance units of the delayed fracture of high-strength bolts and other treatment measures.

(3) According to research data: The delayed fracture of high-strength bolts in steel bridges in highway bridge projects, shedding of macro-influencing factors and the law to carry out scientific analyses, to provide technical guidance for the design and inspection of high-strength bolts in subsequent such projects.

3. High-strength bolt fracture delay related research in highway bridge maintenance

In the study of high-strength bolt fracture delay in highway bridge maintenance project, its key work includes the following aspects.

(1) Research and analysis of the current situation of high-strength bolt fracture delay in steel bridges and the study of its relation to the environment, structural parts, parts of components, bolt parts and characteristics of macro-factors such as the influence of the law.

(2) From the product inspection, design, construction and other aspects of the prevention of high-strength bolt fracture delay in steel bridges, there is a need for effective measures to guide the actual project. In this specific research, several challenges were encountered, particularly in the following aspects.

(i) The study of highway bridge projects requires a certain level of representativeness and an adequate number of high-strength bolts of a certain scale.
(ii) Accurate information on the production, installation, and operational processes of the high-strength bolts in the bridge is necessary.
(iii) It is essential to integrate the research findings with actual engineering practices and propose effective measures to prevent the delayed fracture of high-strength steel bridge bolts [2]. Based on the above research focus and challenges, the team conducted its study on high-strength bolt fracture delay through the following approaches.

3.1. Fracture delay and occurrence mechanism

Fracture delay is a quality damage problem that can easily occur in the continuous application of high-strength bolts. Usually, the main characteristics of such problems are shown in the following aspects.

(1) When the tensile strength of the high-strength bolt fracture delay exceeds 1,226 MPa, the risk of fracture delay will occur.
(2) This situation usually occurs at room temperature conditions [3].
(3) High-strength bolts with delayed fracture usually do not have significant plastic deformation at the microscopic level.
(4) It is also likely to occur under static load conditions.
(5) Such cases also occur at stress levels much lower than the yield point [4].

The main mechanisms of fracture delay are typically manifested in the following aspects.

(1) Corrosion caused by the surrounding environment or hydrogen generated during fabrication entering the steel can lead to brittle failure.
(2) Once hydrogen penetrates the steel, it diffuses, moves, and accumulates at stress concentration points, triggering brittle failure.
(3) The chemical composition of the steel itself does not directly affect its susceptibility to cracking.
(4) The steel's tensile strength, the applied stress, and the environmental conditions all influence the fracture delay.

3.2. Non-destructive testing technology for delayed cracks

Non-destructive testing (NDT) is a key technology for detecting delayed fractures in high-strength bolts used in highway bridge structures. Typically, inspectors use ultrasonic non-destructive testing equipment. The principle of this method involves using an ultrasonic transmitter to send waves into the high-strength bolts and a receiver to capture the waves that return from within the bolts [5]. "Internal integrity and internal cracks in high-strength bolts produce distinct patterns in reflected ultrasonic waves. By analyzing these differences, inspectors can scientifically determine whether there is a fracture delay issue and provide a basis for subsequent replacement or maintenance.

3.3. The current situation of fracture delay

In this study, the researcher carried out non-destructive testing on the high-strength bolts in five major highway bridges in Chongqing, including Dongshuimen Yangtze River Bridge, Qianlizimen Jialingjiang River Bridge, Caiyuanba Yangtze River Bridge, Zengjiayan Jialingjiang River Bridge, and Hongyancun Jialingjiang River Bridge. **Table 1** shows the span composition of steel truss bridges and the number of high-strength bolts in the five major highway bridges studied.

Table 1. The span composition of steel truss bridges and the number of high-strength bolts of the five major highway bridge

Serial number	Name of highway bridges	Span composition (m)	Number of high-strength bolts
1	Dongshuimen Yangtze River Bridge	222.5 + 445.0 + 190.5	820,000 sets
2	Qianlizimen Jialingjiang River Bridge	88.0 + 312.5 + 80.0	645,000 sets
3	Caiyuanba Yangtze River Bridge	102.0 + 420.0 + 88.0	218,000 sets
4	Zengjiayan Jialingjiang Bridge	135.0 + 270.0 + 135.0	632,000 sets
5	Hongyancun Jialingjiang River Bridge	90.0 + 135.0 + 375.0 + 120.0	743,000 sets

Non-destructive testing (NDT) of high-tensile bolts in the highway bridge projects identified fracture issues in the bolts installed on the steel truss bridges of the five studied projects. The proportion of high-tensile bolts with fractures ranged from 0.4% to 26.8% of the total number of bolts in these bridges. The earliest fractures were detected 2 months after the bolts were put into official use, while the latest fractures occurred 9 years after installation.

In this study, fractured high-strength bolts were further tested using Rockwell hardness testing and chemical composition analysis. The results showed that some bolts had Rockwell hardness values exceeding their design specifications. Further analysis indicated that this discrepancy was likely due to the raw materials of the bolts not meeting the actual requirements of the bridge structure or the bolts being in a tensile state for an extended period, which increased their tensile strength [6]. Additionally, some high-strength bolts have chemical compositions that do not meet design specifications, primarily due to the raw materials used not conforming to design standards, as shown in **Table 2**.

Table 2. Results of high-strength bolts after fracture Rockwell hardness and chemical composition test

Serial number	High-strength bolt type	Rockwell hardness	Chemical composition
1	M24	Conformity	Mn content 1.37 (exceeds the specified range 0.50-0.90), V content 0.002 (below specified range 0.05-0.12),
2	M24	Conformity	C content 0.19 (below specified range 0.31-0.39), Mn content 1.47 (exceeds the specified range 0.50-0.90), V content 0.0003 (below specified range 0.05-0.12)
3	M30	Conformity	Conformity
4	M30	40.5 (exceeds specified range 33-39)	Conformity
5	M30	43.0 (exceeds specified range 33-39)	Conformity
6	M30	Conformity	Conformity
7	M30	43.0 (exceeds specified range 33-39)	
8	M30	Conformity	C content 0.18 (below specified range 0.31-0.39), Mn content 1.45 (exceeds the specified range 0.50-0.90), V content 0.0003 (below specified range 0.05-0.12)
9	M30	40.0 (exceeds specified range 33-39)	C content 0.21 (below specified range 0.31-0.39), Mn content 1.47 (exceeds the specified range 0.50-0.90), V content 0.0003(below specified range 0.05-0.12)
10	M30	40.0 (exceeds specified range 33-39)	Conformity
11	M30	43.0 (exceeds specified range 33-39)	Conformity

Note: Mn = Manganese, V = Vanadium, C = Carbon

3.4. Fracture delay research conclusions

After conducting fracture delay NDT and analyzing high-strength bolts from the steel truss bridges in five major highway bridge projects in Chongqing using the above methodology, the following research conclusions were obtained.

(1) The earliest bolt fractures occurred either before the bridges were opened or shortly after their opening, and no clear correlation between the operational time and fracture timing was found.

(2) Both M30 and M24 bolts experienced fractures, suggesting that the diameter of the bolts may not be directly related to delayed fracture issues.

(3) The main locations of high-strength bolt fractures were concentrated near the supports and the center of the span in arch ribs, while fractures in the main girders were more scattered [7].

(4) Test results for chemical composition and Rockwell hardness after fractures indicated that some bolts did not meet the specified values, highlighting the need for more rigorous testing during steel beam installation.

3.5. Recommendations for the maintenance of high-strength bolts

Based on the conclusions drawn from the study of delayed fractures in high-strength bolts used in highway and bridge projects, and considering the practical needs of modern highway and bridge applications, the following recommendations are proposed.

(1) Post-operational non-destructive testing: After the highway and bridge projects are officially put into operation, staff should implement non-destructive testing of high-strength bolts by means of random testing or regular testing to promptly identify any fractures. This testing helps detect fracture delays early and allows for timely intervention based on the actual conditions [8].

(2) Maintenance and environmental control: During the operation and maintenance of these structures, staff should ensure thorough cleaning of the bolt locations to prevent dust, oil, and other contaminants, creating a clean operating environment. Additionally, controlling environmental humidity and removing water from around the bolts are essential to prevent corrosion and subsequent fracture delays [9].

(3) Inspection of anti-corrosion coatings: Regular inspections of the anti-corrosion on high-strength bolts should be conducted. For bolts with damaged coatings, timely re-coating is necessary to protect against corrosion and maintain the bolts' quality and strength.

(4) Material selection for replacements: When replacing high-strength bolts, staff should select materials that meet the specific engineering design requirements to avoid fracture delays caused by poor material quality.

By implementing these measures, maintenance of high-strength bolts in steel structure beams of highway bridge projects can be effectively managed, reducing the incidence of fracture delays and ensuring the quality and safety of the structures [10].

4. Conclusion

In summary, high-strength bolts are critical connecting components in many modern highway and bridge projects. When high-strength bolts experience fracture delays, their quality and strength can be significantly compromised, potentially leading to damage that adversely affects the safe and stable operation of these projects. To prevent such issues, it is essential for operation and maintenance units to focus on researching the mechanisms and causes of high-strength bolt fractures. Based on this research and the specific conditions of highway and bridge projects, reasonable measures should be implemented to ensure effective maintenance of high-strength bolts. By doing so, the overall quality and performance of these bolts can be enhanced, contributing to the stability and safety of modern highway bridge steel girder structures and extending their service life.

Disclosure statement

The author declares no conflict of interest.

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Digital Application of BIM Technology in the Architectural Design Stage

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Abstract: This paper discusses the digital application of building information model (BIM) technology in the architectural design stage. Taking the large-scale comprehensive development project of Guangxi headquarters base as an example, this paper analyzes in detail how BIM technology promotes the intelligence and refinement of the design process. Through the three-dimensional modeling and simulation analysis of BIM technology, the project design has realized the accurate transformation from concept to operation, which not only improves the design efficiency, but also ensures the construction quality and economic benefits. This paper focuses on the application of BIM in the digital design of building structure, the deepening design of steel nodes, as well as the remarkable results in the comprehensive layout optimization of mechanical and electrical pipelines. Through the collision detection and optimization design of the BIM model, the potential design conflicts and construction problems were found and solved at the initial stage of the project, ensuring the efficient promotion and smooth implementation of the project. The research results show that BIM technology, as the core digital tool in the architectural design stage, is of great significance for improving the overall design level of the construction industry and realizing intelligent construction.

Keywords: BIM technology; Digital application; Architectural design

Online publication: September 23, 2024

1. Introduction

With the rapid development of the construction industry and the rapid development of technology, BIM technology, as an important driving force for the digital transformation of the construction industry, is gradually becoming the core tool to improve design efficiency, optimize construction process and strengthen project collaborative management [1].

By building a three-dimensional digital model, BIM technology not only integrates the information of the whole life cycle such as architectural design, construction, operation and maintenance, but also realizes information sharing and interoperability, providing solid technical support for the scientific management and efficient implementation of construction projects. In the architectural design stage, the application of BIM technology is particularly critical. It breaks the limitation of the traditional two-dimensional design mode, intuitively shows the design concept in the three-dimensional form, and greatly improves the design quality and expression accuracy

[2,3]. Through the BIM model, the designer can review the design scheme in an all-round and multi-angle way, find and correct the problems in the design in time, and avoid the changes and rework in the later construction. Simultaneously, the data in the BIM model is rich and accurate, which provides strong data support for design optimization, cost estimation and resource allocation, and helps the project team to make better decisions and planning. Additionally, the application of BIM technology in the architectural design stage also promotes multi-professional collaboration. Through the BIM platform, professional designers can share models and data, realize real-time communication and feedback, effectively reduce design conflicts and misunderstandings, and improve design efficiency and achievement quality [4,5].

This paper will take the large-scale comprehensive development project of Guangxi headquarters base as an example, systematically explain the digital application practice of BIM technology in the architectural design stage, discuss its application effect and advantages, and look forward to its future development prospects, in order to provide strong support for the digital transformation and intelligent upgrading of the construction industry.

2. Project introduction

2.1. Project overview

This project is a large-scale comprehensive development project located in the headquarters base of Guangxi, whose core goal is to create a modern area integrating residential, office and educational functions. The total area of the project is 92,100 m^2, while the total construction area is 379,700 m^2. Specifically, the above-ground construction area is about 292,500 m^2, and the underground construction area is 87,200 m^2. The diversity of architectural forms is a major feature of the project, which includes high-rise residences, office buildings with frame-core tube structures, frame service centers and commercial facilities. These architectural forms not only enrich the skyline of the area, but also constitute a fully functional modern comprehensive development area.

The project consists of 23 single buildings, whose design and planning reflect a deep understanding of the concept of modern urban complex. The project renderings (as shown in **Figure 1**) further demonstrate this grand blueprint, in which the detailed planning and diversified functional layout highlight the design concept of the project. The BIM model, as the digital core of the project design, transforms this grand blueprint from a concept to an operational reality. Through the 3D modeling and simulation analysis of BIM technology, not only accurately restore every detail of the design effect diagram, but also add rich data information and interaction functions on this basis. Moreover, the BIM model also has strong collision detection and optimization design capabilities, which can find and solve potential design conflicts and construction problems at the early stage of the project to ensure the efficient promotion and smooth implementation of the project.

Figure 1. Project renderings

2.2. Key points and difficult points of the project

2.2.1. The project scale is large and the construction cycle is urgent

The total construction area of the project is 379,700 m^2, integrating residential, education, service and business, forming a complex and large professional span, covering many key fields such as weak current, strong electricity, water supply and drainage. In view of the urgent construction time, how to efficiently complete the design, construction and coordination of large-scale and multi-type buildings in a limited period has become the primary challenge.

2.2.2. Optimization of the comprehensive layout of complex pipelines

The basement area as the equipment concentration and parking space, the mechanical and electrical pipeline arrangement is particularly critical. In the face of problems such as multi-professional pipeline interweaving and limited space, it is necessary to realize the efficient integration and orderly layout of pipelines through fine comprehensive pipeline design, which should not only ensure the convenience of operation and maintenance, but also give consideration into the maximization of beauty and space utilization, so as to ensure the comprehensive realization of building functions.

3. Digital application of project BIM

3.1. Digital design of building structure based on BIM

The application of BIM technology in the digital design of building structure is not only a profound innovation of the traditional design process, but also an important driving force for the transformation of the construction industry into being intelligent and refined. BIM technology, with its powerful 3D modeling, simulation optimization and information integration capabilities, has brought unprecedented convenience and efficiency to the building structure design.

3.1.1. Accurately reserved building holes

In building structure design, according to the pipeline comprehensive adjustment and optimization, using the BIM software for pipeline, through the wall reserved hole position planning, can generate in the early construction accurate reserved hole drawings, which not only can help accurately determine the number of the reserved hole, elevation and size of the accuracy, avoid material waste caused by improper hole setting and rework problems caused by construction delay, but also greatly improve the construction quality and economic benefits of the construction project.

3.1.2. Deepening design of reinforcement nodes assisted by BIM

In order to improve the accuracy and efficiency of the reinforcement construction, the BIM platform is used to build the structural reinforcement model of the whole or specific parts of the project. A detailed drawing of reinforcement nodes is generated through the combination of plug-in assistance and manual fine adjustment. Furthermore, the visual characteristics of the BIM model are used to make the visual disclosure materials to provide intuitive and clear construction guidance for the site construction personnel. This strategy not only reduces the error rate in the construction process, accelerates the construction progress, but also effectively reduces the waste of steel bar materials, and improves the overall construction efficiency, as shown in **Figure 2**.

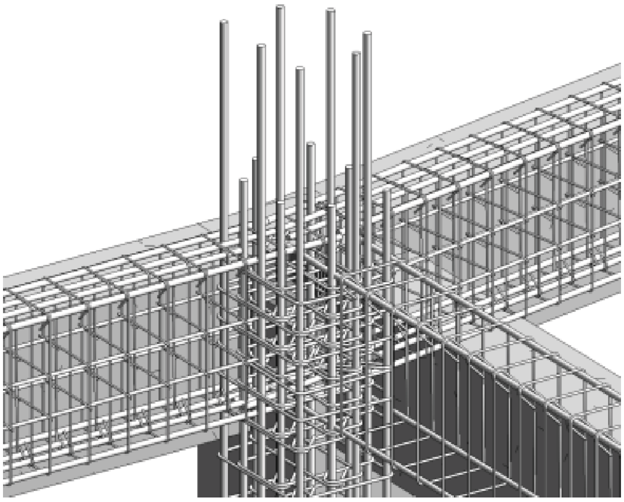


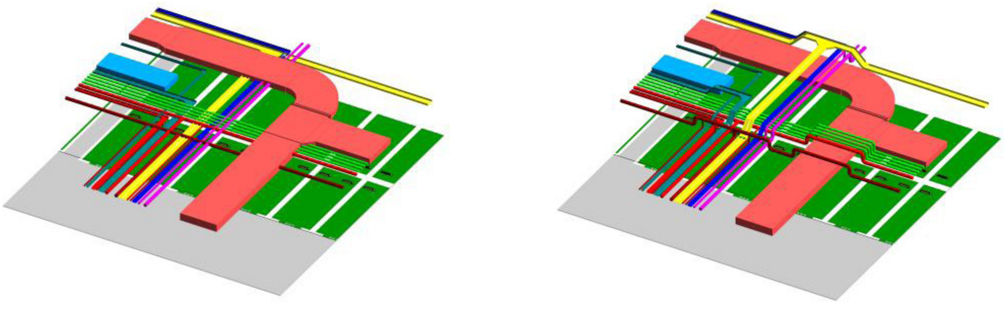
Figure 2. Steel bar node of beam and column

3.2. Electromechanical digital design based on BIM technology

The application of BIM technology in the integrated deepening design of electromechanical pipelines is one of the most extensive and effective fields in BIM practice. It not only involves many professional cross operations, such as heating, ventilation, and air conditioning (HVAC), water supply and drainage, fire protection, strong and weak electricity, and many more, but also requires the centralized arrangement and dense direction of pipelines in the limited space, which brings quite high difficulty in the design and construction. Especially in high-rise buildings or large comprehensive buildings, the comprehensive arrangement of pipelines should not only meet the requirements of functionality and safety, but also take into account the beauty, the convenience of maintenance and the maximum use of the building space.

3.2.1. Pipeline comprehensive optimization design

Based on the integration of full-professional (architecture, structure, electromechanical, etc.) BIM model, a comprehensive collision detection is conducted through BIM software to accurately identify the potential conflicts within the pipeline, between the pipeline and equipment, and between the pipeline and structure. After the collision inspection is completed, a detailed collision report will be automatically generated to clearly mark the location and nature of the collision point. According to the collision report, combined with the construction feasibility, decoration requirements, mandatory specifications and operation and maintenance convenience, the design team proposed the pipeline layout optimization scheme, as shown in **Figure 3**. The scheme aims to realize the scientific, rationalization and aesthetics of pipeline horizontal and vertical layout, to ensure the smooth construction and meet the final use needs.



(a) Before optimization (b) After optimization

Figure 3. Pipeline synthesis

3.2.2. Comprehensive and deepening adjustment of the pipeline

The net height analysis is conducted with BIM software to accurately evaluate whether the net height of each functional area meets the national norms and standards. This step is crucial to ensure the functionality and compliance of the building space. If the net height deficiency is found, the design team will communicate with the owner in time to ensure that the project passes the acceptance smoothly and meets the delivery standards by adjusting the pipeline layout and optimizing the height of the ceiling.

4. Conclusion

Through a thorough analysis of the application of BIM technology during the construction design stage of large-scale comprehensive development projects at the Guangxi headquarters base, this paper draws the following conclusions. Firstly, BIM technology with its robust 3D modeling, simulation optimization and information integration capabilities, has provided unprecedented convenience and efficiency in architectural design. It has significantly improve design quality and construction efficiency. Secondly, in building structure digital design, BIM technology enables accurate reservation of building openings and detailed design of steel nodes, which effectively reduces error rates and material waste during construction, thereby enhancing economic benefits. Finally BIM technology's collision detection and optimization design functions are crucial for the comprehensive layout of mechanical and electrical pipelines. These functions ensure scientifically rational and aesthetically pleasing pipeline arrangements while meeting building functionality and safety requirements. In summary, the digital application of BIM technology in the architectural design stage not only fosters the intelligent transformation of the construction industry but also provides vital support for achieving sustainable architectural design. With the ongoing development and enhancement of BIM technology, its application prospects in architectural design are expected to be even broader in the future.

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Study on Influencing Factors and Control Points of Design Estimate of Landscaping Engineering

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Abstract: In recent years, China's landscaping projects have developed vigorously, and the growth rate of urban garden green space areas has been maintained at about 5%. Overall, with the development of the national economy and the support of macro policies, people's demand for close to nature and beautify the environment is gradually increasing, which has brought new growth momentum for the development of the landscaping industry. Simultaneously, from the perspective of future economic development and urban development, the landscaping industry still has a lot of room for development. However, with the rapid development of landscape engineering, the problem of cost control of landscape engineering is becoming more prominent, the phenomenon of budget overestimation is common, and there are many factors affecting the cost of landscape engineering, which brings difficulties and challenges to the analysis of its influencing factors and cost management. How to scientifically analyze the influencing factors and control the cost has become an important link in the landscaping project. To solve the above problems, this paper takes the design stage of landscaping engineering as the background, takes the design estimate of landscaping engineering as the research object, through literature research and data collection, fully excavates the main influencing factors of the design estimate stage of landscaping engineering, analyzes the key points of cost control, and provides reference ideas and directions for the later cost management and control.

Keywords: Landscape engineering; Design estimate; Main influencing factors; Cost control

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1. Background and significance of the topic

1.1. Background of the topic

With the concept of "Jinshan Yinshan" (golden mountains and silver mountains) deeply rooted in people's hearts, China's landscaping projects have experienced vigorous development. People are increasingly focused on the construction of these projects, which not only play a crucial role in social and economic activities but also significantly contribute to economic and cultural development, enriching people's spiritual life. However, with the rapid development of landscaping projects in China, the problems existing in cost estimation and control also become prominent.

The “three super” phenomenon—namely budget overestimation, budget overruns, and final account overbudget—occurs from time to time. Many uncertain factors affect the construction cost of landscaping projects, including local hydrogeological conditions, regional differences in seedling prices, variations in planting and maintenance practices among construction personnel, extended management and protection periods, and high risks. These factors present difficulties and challenges in analyzing influencing factors and management costs for landscaping projects [1].

To solve the above problems, this paper takes the design stage of landscaping engineering as the background, takes the design estimate of landscaping engineering as the research object, through literature research and data collection, fully excavates the main influencing factors of the cost of landscaping engineering design stage, analyzes the key points of cost control, and provides reference ideas and directions for cost management and control.

1.2. Significance of topic selection

Through literature research and data collection, effective method support and theoretical support are provided for the influencing factors and cost control of landscaping engineering in the design stage, which has important theoretical and practical significance as follows [2].

(1) The cost control of landscaping engineering is mainly concentrated in the three stages: design, bidding, and construction. The analysis finds that the impact of the design stage on project cost accounts for about 75%, so the research on the influencing factors and control points of the design stage provides theoretical support and management direction for later project management costs [3].

(2) Scientific analysis of the influencing factors and control methods of landscaping engineering in the design stage is not only conducive to the control of the whole process cost of the project but also conducive to promoting the healthy and rapid development of the industry and promoting stable economic growth.

1.3. Main research contents and ideas

The extensive collection, sorting, and analysis of a large number of similar engineering design estimates, statistical analysis, literature research, and historical case analysis are used to excavate and analyze the influencing factors of landscape greening engineering design estimates, to provide the basis for subsequent engineering cost control.

1.4. Main research methods adopted

1.4.1. Literature research method

The literature research method is a method to collect, identify, and sort out the literature, analyze, and study the referable literature, to understand the objective cognition of the transaction. This paper will use the literature research method to analyze and study the engineering estimation and cost control domestically and internationally, and combined with the research direction of this paper, analyze the influencing factors and control points of the design budget of landscaping engineering [4].

1.4.2. Systematic analysis

The systematic analysis method refers to the problem solved as a system, carries out a comprehensive analysis of various elements in the system, and summarizes, and comprehensively understands the characteristics of the object studied and the rule relationship between them. In the whole research process of this paper, the method of systematic analysis is always used. In the selection process of impact indicators, the factors affecting the design budget of landscaping engineering are listed as many as possible, and then the influencing factors are classified and sorted by the concept of systematic analysis. Finally, the main factors affecting the design budget of landscaping engineering are determined by systematic analysis and other methods followed by forming the index system that affects the cost [5].

1.5. Research objectives to be achieved

Through analyzing the design budget estimate and project examples of landscaping engineering, and using statistical analysis, literature research, and other methods, the main factors affecting the design budget estimate of landscaping engineering are dug out, and the control points of the cost of landscaping engineering are analyzed. This provides data support for the budget personnel engaged in landscaping engineering and provides ideas and directions for the early decision-making and cost management of landscaping engineering.

2. Related concepts of design estimates

2.1. Basic concept of design estimate

The design estimate is an important part of the design document. It is a document prepared by the design unit based on the preliminary design (expansion preliminary design) drawings, budget quota (budget estimate index), cost quota, and budget price of equipment and materials in the construction area from preparation to completion and delivery of all costs [6].

2.2. Contents of the design estimate

The design budget estimate can be divided into three levels: unit project budget estimate, comprehensive budget estimate of a single project, and total budget estimate of the construction project [7].

2.2.1. Unit project budget

The unit project refers to a project with relatively independent construction conditions, it is a component of a single project. The budget estimate of a unit project is generally composed of budget estimate quota or budget quota group price. From the perspective of cost composition, it can be divided into labor costs, materials costs, machinery costs, enterprise management fees, profits, and so on. It is the basic unit that constitutes the design estimate [8].

2.2.2. Budget estimate of a single project

The “single project” refers to a project with independent design documents, which has a certain production capacity or is put into operation after completion. It is an integral part of the construction project.

The comprehensive budget estimate document of a single project generally includes a preparation description, a comprehensive budget estimate table, and a unit project budget estimate table. The contents include the budget estimate of the construction project, the budget estimate of the equipment and installation project, and other costs of the construction project.

2.2.3. Total budget estimate of the construction project

A construction project is the sum of one or more individual projects that are built according to a master plan or design.

The contents of the preparation of the total budget estimate of the project include the preparation description, the total budget estimate table, the comprehensive budget estimate table of a single project, the other cost estimate table, and the summary table of the main construction equipment and materials. The main contents are engineering expenses, other expenses of engineering construction, reserve expenses, interest on construction loans, and working capital.

2.3. Principles and basis for the preparation of design budget estimates

The principles and basis for the preparation of the design budget estimate are as follows [9].

(1) Laws, regulations, and provisions of the state, industry, and local government on construction and cost management.

(2) Relevant documents and fee information, including the following.

(i) Preliminary design or expansion of preliminary design drawings, design specifications, equipment lists, and material lists.

(ii) The approved construction project design plan (or the approved feasibility study report) and the relevant provisions of the competent authorities.

(iii) the current budget estimates and budget quotas of the state or provinces, cities, and autonomous regions.

(iv) Labor wage standards, material prices, construction machinery class prices, standard equipment, and non-standard equipment price information, the current equipment price and transportation and miscellaneous costs, and all kinds of cost information and indexes in the construction project area.

(v) Other information involved in the project.

(3) Construction site information, including the following.

(i) Construction site, terrain, local project construction, and construction costs.

(ii) Natural conditions such as climate, hydrology, geology, and geomorphology of the area where the project is located.

(iii) Other information involved in the project.

3. Analysis of influencing factors and control points of design budget of landscaping engineering

3.1. Analysis of influencing factors of landscaping engineering design budget

Currently, the budget estimate of landscaping engineering design is based on the budget quota, which is analyzed to determine the overall budget. According to the content of "Code for Calculation of Engineering Quantity of Landscaping Engineering," combined with the method of engineering quantity list, it can be divided into earth and rock engineering, greening engineering, garden road and bridge engineering, garden landscape engineering, installation engineering, etc. The construction content of landscaping engineering is diverse, the budget subitems are more and do not repeat each other, and the setting of sub-purposes can cover the whole project content [10]. In this paper, the analysis principle of influencing factors is illustrated by taking pavement subitems and greening subitems of garden road as examples.

3.1.1. Analysis of influencing factors of the subhead of pavement budget

The subproject cost of garden road pavement accounts for about 20% to 40% of the cost of the entire landscaping project, of which the grass-roots approach of pavement subproject and the choice of surface paving material will affect the project cost.

Different load requirements directly affect the selection of material and thickness of the garden base. To prevent road damage and reduce the maintenance cost in the later period, a reinforced concrete cushion layer is usually added to the road base based on pond slag backfilling. For non-motor vehicle pavement, because of its small bearing capacity, usually adds gravel cushion or plain concrete cushion after plain soil backfill. Under the condition of satisfying the load, reducing the thickness of the base appropriately will reduce the cost.

Using the base of a park road in Shijiazhuang as an example, during the preliminary design estimate stage, the base design included 300 mm thick graded gravel and 180 mm thick plain concrete. The cost for one square meter of the base was 146.2 yuan. In the later stage, the designer optimized the construction drawings, adjusting the base to 200 mm thick gray soil (3:7 ratio) and 150 mm thick plain concrete. The cost for one square meter of the base was 112.64 yuan. With a park area of 9,016 m^2, this adjustment reduced the total cost by 302,600 yuan. For example, the comprehensive unit price of plain soil backfill is 17 yuan/m^3, while the comprehensive unit price for pond slag backfill is 68 yuan/m^3. This results in a difference of 51 yuan/m^3. Therefore, the choice of material and thickness of the garden road base is a major factor affecting the cost of paving in landscape greening projects [11].

Different surface materials and thicknesses have a direct impact on the price of surface materials. The material cost of square bricks and embedded grass bricks is lower than that of granite. For the same type of material, the cost of the surface layer increases with thickness. For example, for granite with a thickness of less than 80 mm, and with other parameters unchanged, every 10 mm increase in thickness results in a 10% to 30% rise in material cost.

Using Wenjingshan Park as an example, granite was used for the pavement and parking lot in the preliminary design stage, with a cost of 380 yuan/m^2. In the construction drawing stage, designers incorporated the concept of a sponge city, changing the parking lot pavement to inlaid grass bricks and the sidewalk to permeable concrete. Both inlaid grass bricks and permeable concrete are effective 9garden pavement materials that are permeable and breathable, which can reduce the burden on urban drainage systems, and they have lower costs. The sidewalk area in Wenjingshan Park is 49,412 m^2, and the parking lot area is 3,440 m^2. The total cost for paving with granite is 18,601,400 yuan. In contrast, using permeable concrete and inlaid grass bricks results in a total cost of 11,489,800 yuan, leading to savings of 7,111,600 yuan in construction funds [12]. The factors influencing pavement engineering characteristics include the base material and thickness, surface material thickness, and the area of the garden road.

3.1.2. Analysis of influencing factors in greening budget

Greening engineering is a core component of landscaping projects, and the types and specifications of seedlings used in greening subitems can significantly affect the cost [13].

Seedling varieties in landscaping projects can be categorized into trees, shrubs, flowers, lawns, etc., and the costs of these seedlings vary significantly. For example, large trees generally cost over 1,000 yuan each, with prices potentially reaching nearly 10,000 yuan. Small shrubs, such as hibiscus trees, are priced at around 100 yuan each, typically between 30 to 100 yuan. When selecting seedling varieties, it is important to consider aesthetics, achieve the desired effect, and manage costs effectively.

Within the same seedling variety, prices can differ based on specifications. For trees, the diameter at breast height (DBH) is a key factor affecting cost. For instance, when the DBH exceeds 40 cm, each additional 5 cm can increase the price by about 30%. For example, a Fadong tree with a 25cm DBH costs approximately 3,600 yuan, while a tree with a 40 cm DBH can cost around 10,000 yuan.

Additionally, the cost of maintaining seedlings varies with different aintenance periods. For instance, the annual management fee for trees with a DBH below 80 cm is 39.52 yuan per plant. Extending the maintenance period to two years increases the cost to 79.04 yuan per plant. Thus, each additional year of maintenance adds 39.52 yuan to the cost per plant.

In summary, the key influencing factors for greening engineering costs are seedling varieties, seedling specifications, maintenance cycles, and seedling quantity. Other budget subitems in landscaping projects are influenced by similar factors and will not be repeated here.

3.2. Analysis of key points of cost control of landscaping engineering during the design stage

To effectively manage the cost of landscaping engineering, it is important to analyze the influencing factors in the design and identify key points for cost control. Currently, the main aspects of cost control during the design stage of landscaping engineering include limit design and life cycle cost analysis.

3.2.1. Limit design

The quota design of a landscaping project is to complete the design to meet the function of garden construction under a certain investment quota. It divides the investment quota and engineering quantity into each unit project and division project and strictly controls the allocation quota. Investment decomposition and engineering quantity control are the basic means of quota design. The main measure of the quota in the design is to control the engineering quantity of the design content and to choose the scheme according to the influence factors analyzed above, which can effectively control the project cost [14].

3.2.2. Life cycle cost analysis

The life cycle cost analysis of landscape engineering refers to the process of selecting the best design scheme through the in-depth analysis of the start-up cost, construction cost, and late operation and maintenance cost of different schemes of landscape projects [15].

4. Conclusion

Combining the characteristics of complex construction content and diversified quota subitems, this paper analyzes the landscaping project based on the design estimate and engineering quantity calculation standard of the landscaping project and obtains the main influencing factors and control points that affect the design estimate of the landscaping project by typical case analysis. The main conclusions are as follows.

(1) Taking the design estimate of landscaping engineering as the research object, through literature collection and data analysis, the main influencing factors affecting the pricing unit with research value are finally determined.

(2) According to the excavated main factors affecting the design budget estimate and the analysis of a large number of historical cases, the control points of the design budget estimate of landscaping engineering are obtained. It provides the theoretical direction for pre-project decision-making and cost control.

Disclosure statement

The authors declare no conflict of interest.

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Comparative Analysis of Differences among Northern, Jiangnan, and Lingnan Classical Private Gardens Using Principal Component Cluster Method

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Abstract: This paper investigates the design essence of Chinese classical private gardens, integrating their design elements and fundamental principles. It systematically analyzes the unique characteristics and differences among classical private gardens in the Northern, Jiangnan, and Lingnan regions. The study examines nine classical private gardens from Northern China, Jiangnan, and Lingnan by utilizing the advanced tool of principal component cluster analysis. Based on literature analysis and field research, 273 variables were selected for principal component analysis, from which four components with higher contribution rates were chosen for further study. Subsequently, we employed clustering analysis techniques to compare the differences among the three types of gardens. The results reveal that the first principal component effectively highlights the differences between Jiangnan and Lingnan private gardens. The second principal component serves as the key to defining the types of Northern private gardens and distinguishing them from the other two types, and the third principal component indicates that Lingnan private gardens can be categorized into two distinct types as well.

Keywords: Classical gardens; Private gardens; Differences; Principal component analysis; Cluster analysis

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1. Research background and objectives

Private gardens occupy a crucial position in the long history of garden art in China. They are not only an essential component of garden art but also a fusion of multiple factors, including history, culture, and art. Over five thousand years of civilization have given rise to a unique artistic style in Chinese classical gardens [1]. Many scholars have researched Chinese classical gardens from various perspectives. However, current studies often focus on qualitative analysis, primarily relying on textual descriptions supplemented by images, while quantitative research on the regional differences of classical gardens remains insufficient [2,3]. Traditional comparative research often relies on heuristic methods, where scholars articulate design theories and principles based on personal understanding and experience, a process that carries subjective biases [4]. Comparative research on the differences between different types of classical Chinese gardens through statistical methods can address classification issues. Additionally, through exploratory data analysis, researchers can be inspired to explore new directions and perspectives in their studies.

To achieve this objective, this paper builds upon previous research and delves into the coordinating mechanisms among the design elements, geographical locations, design principles, and related landscape design elements of classical private gardens. Through a comprehensive literature review and field research, we systematically collected relevant variables and employed statistical analysis methods, aiming to precisely analyze the differences and characteristics in the design elements and principles of private gardens in Northern China, Jiangnan, and Lingnan.

2. Research objects

China boasts a long history of private gardens, and while Jiangnan gardens are renowned, unique private gardens can also be found in other regions, each representing the local characteristics of private gardens. Therefore, from the perspective of regional representation, this research selects representative gardens as analysis samples to explore the unique styles and differences of private gardens in the three major regions: Northern China, Jiangnan, and Lingnan. The selected gardens include Prince Chun's Garden, Prince Kung's Garden, and Beile (A title used for royal princes or nobility in historical China) Tao's Garden, all of which embody the characteristics of Northern private gardens in Beijing. The Humble Administrator's Garden, Lingering Garden, and Lion Grove Garden showcase the features of Southern private gardens in Suzhou, Jiangsu Province, and the Ke Garden in Dongguan and Qinghui Garden, as well as Liang Garden in Foshan, which represent the characteristics of Lingnan private gardens. The collection of all garden elements is based on literature reviews and on-site photographs, resulting in a total of 273 original variables. The selection of variables focuses on various garden design elements and influencing factors, such as architecture, water features, stones, pavements, plants, geographical locations, design principles, and other related landscape design elements [4].

3. Research methodology

Cluster analysis is a data classification method based on the principle of similarity, which aims to identify similar and dissimilar groups from a set of objects. Within the same cluster, objects exhibit a high degree of similarity to each other, while significant differences exist between different clusters [5]. This approach not only promotes the intuitive understanding of relationships between objects but also dramatically enhances the efficiency of data analysis.

To conduct the cluster analysis, we first utilized Statistical Package for the Social Sciences (SPSS) statistical analysis software to perform Principal Component Analysis (PCA) on all elements. The core function of PCA is to condense data, which reduces the original multiple variables to a few principal components through mathematical transformations. When the eigenvalues of these principal components exceed 1, and their cumulative contribution rate reaches a predetermined percentage threshold, it can be considered that these principal components effectively capture most of the critical information in the original data [6–9].

Based on the loading matrix established by SPSS software, the characteristic vectors of each variable can be calculated using the following formula [10]:

$$K_n = \frac{a_n}{\sqrt{x_n}} \quad (1)$$

Subsequently, we standardized all variables using the means and standard deviations obtained from SPSS software. This process involves subtracting the mean of each variable from its original value and dividing it by its standard deviation, thereby transforming the data into values with a zero mean and unit variance. This aims to eliminate the influence of different units of measurement on data analysis, as illustrated in the following formula [11]:

$$Z_n = \left(\frac{x_n - \overline{x_n}}{SD_n}\right) \quad (2)$$

After obtaining all the data, the scores of each plot on a specific principal component can be calculated, and the comprehensive score can be obtained by weighing through the contribution rates, as shown in the following formula [11]:

$$\text{Garden score} = f(x) = \sum_{n=1}^{n} (Z_n \times K_n) \quad (3)$$

where n=1,...273, x_n represents the eigenvalue of the variable, $\overline{x}_n$ is the mean of variables, SD_n denotes the standard deviation of variables, Z_n is defined as the standardized variable value, a_n represents the load of the variable, and K_n is the eigenvector corresponding to the principal component eigenvalues.

4. Results and analysis

4.1. Principal component analysis

We conducted an in-depth data analysis using the SPSS statistical analysis software on 273 landscaping element variables covering nine private gardens. **Table 1** demonstrates the eigenvalues and contribution rates of each principal component. The variance contribution rates explained by the eigenvalues of the first four principal components reached 26.691%, 20.704%, 14.176%, and 10.863%, respectively [12–14]. The cumulative contribution rate of these four principal components reaches 72.434%, indicating that they collectively account for over 70% of the information from the original data. In contrast, the contribution rates of the 5th to 8th principal components to the variance are below 10%, suggesting a relatively limited impact. Therefore, we focus on the first four principal components to explore the differences among private gardens in the North, Jiangnan, and Lingnan regions.

Table 1. Eigenvalues and contribution rates of each principal component

Principal component	Eigenvalue	Contribution rate (%)	Cumulative contribution rate (%)
1	72.866	26.691	26.691
2	56.523	20.704	47.395
3	38.701	14.176	61.571
4	29.657	10.863	72.434
5	23.344	8.551	80.985
6	19.593	7.177	88.162
7	18.492	6.774	94.936
8	13.826	5.064	100.000

Factor loadings serve as essential metrics for assessing the degree of correlation between principal components and their corresponding original variables. In general, a greater absolute value indicates a stronger explanatory capacity of the principal component regarding the respective indicator variable [15,16]. **Table 2** details the loading matrices, means, and standard deviations for the first four principal components, where factor loadings with absolute values exceeding 0.3 are typically considered statistically significant. **Table 2** reveals that the first four principal components encompass three types of loadings: positive, negative, and zero. In the dimensions of the first four principal components, the dependent variables can be categorized into a positive set that is meaningfully related to the axis, a negative set that is meaningfully related to the axis, and a zero set that is related to both the positive and negative sets on the axis. Additionally, the SPSS software provides the mean and standard deviation information for all variables.

After completing data processing in SPSS, we used the obtained variable values, means, standard deviations, and principal component coefficients to construct a corresponding mathematical model to calculate the scores of the nine gardens. The results of this process are organized in **Table 2**.

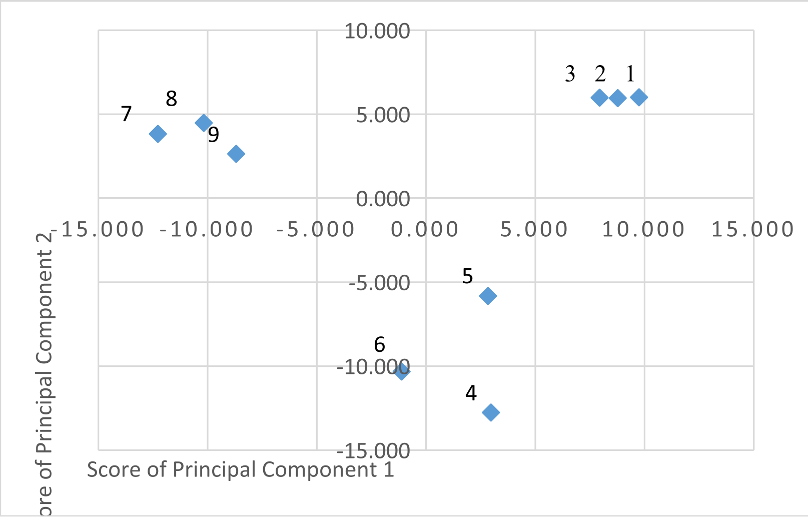
Table 2. Scores of the nine Gardens on the first four principal components

Principal component	Humble Administrator's Garden	Lingering Garden	Lion Grove Garden	Prince Chun's Garden	Prince Kung's Garden	Beile Tao's Garden	Ke Garden	Qinghui Garden	Liang Garden
1	9.747	8.773	7.942	2.969	2.832	-1.119	-12.275	-10.177	-8.692
2	6.006	5.959	5.982	-12.760	-5.818	-10.317	3.828	4.480	2.639
3	0.106	-0.906	0.804	11.947	-3.070	-11.850	3.858	-0.081	-0.807
4	-0.827	-1.319	-1.778	-0.558	8.283	-5.923	-8.389	4.239	6.271

4.2. Cluster analysis

Scatter plots are used for the visual identification of clusters. The horizontal axis displays the scores of the nine gardens on one principal component, while the vertical axis corresponds to their scores on another principal component. By comparing them pairwise, we found distinct clustering characteristics when comparing Principal components 1 and 2, 2 and 3, and 1 and 4.

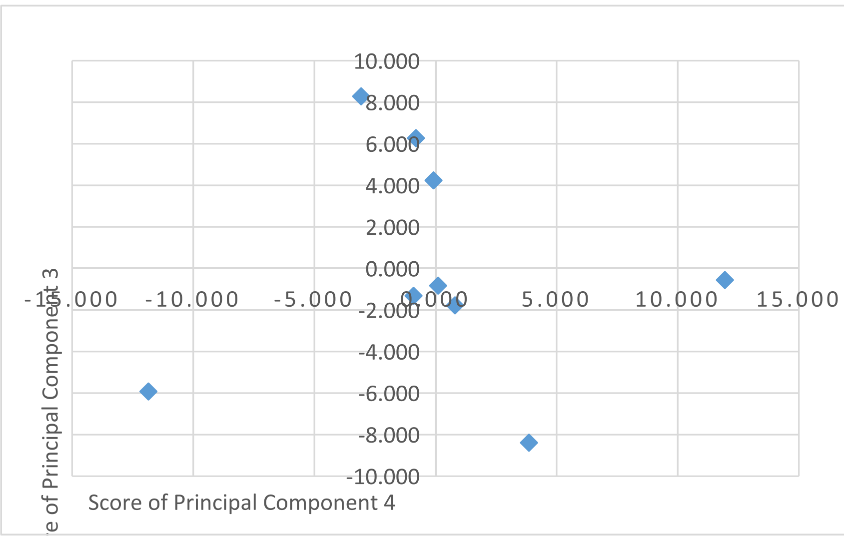
Specifically, **Figure 1** reveals that the nine gardens can be distinctly classified into three categories. On the horizontal axis, there are three categories, including the Jiangnan private gardens cluster in the positive direction, with three gardens scoring closely together, the Lingnan gardens cluster in the negative direction, far from the Jiangnan private gardens, and the Northern gardens cluster near zero value, with positive and negative distributions, and there is no apparent clustering. This indicates that Principal component 1 primarily captures the dimensional information that distinguishes Jiangnan from Lingnan's private gardens. On the vertical axis, the gardens cluster into two categories. One category is in the positive direction, comprising three Jiangnan gardens and three Lingnan gardens and the other category is in the negative direction, including three Northern gardens, further confirming the significant role of Principal component 2 in defining the differences between Northern gardens and the other two categories.



1. Humble Administrator's Garden
2. Lingering Garden
3. Lion Grove Garden
4. Prince Chun's Garden
5. Prince Kung's Garden
6. Beile Tao's Garden
7. Ke Garden
8. Qinghui Garden
9. Liang Garden

Figure 1. Scatter plot of relationships among the nine gardens based on scores of Principal components 1 and 2

By observing the scatter plot in **Figure 2**, we can draw the following conclusions. On the horizontal axis, the distribution of the three Northern private gardens appears to be quite dispersed, with significant distances between them, and they do not clearly distinguish between Jiangnan and Lingnan gardens. This suggests that Principal component 3 is not a precise dimension for judging the differences among these three types of gardens. However, the situation is different on the vertical axis. The three Jiangnan private gardens are closely clustered together. In contrast, the three Northern private gardens and three Lingnan private gardens are more widely dispersed. The Lingnan private gardens are further divided into two categories, with Qinghui Garden and Liang Garden concentrated in the positive vertical direction, while Ke Garden is distanced in the negative direction, suggesting that the fourth principal component may play a crucial role in distinguishing the different types within the Lingnan private gardens.



1. Humble Administrator's Garden
2. Lingering Garden
3. Lion Grove Garden
4. Prince Chun's Garden
5. Prince Kung's Garden
6. Beile Tao's Garden
7. Ke Garden
8. Qinghui Garden
9. Liang Garden

Figure 2. Scatter plot of relationships among the nine gardens based on scores of Principal components 3 and 4

Table 3 to **Table 5** provide a detailed list of positive, negative, and zero variables with absolute factor loadings exceeding 0.3 among the first four principal components. In particular, those variables with absolute factor loadings greater than 0.7 are highlighted with underlines [17]. According to the scatter plot, the positive variables in **Table 3** are primarily associated with the characteristics of Jiangnan private gardens, while the negative variables are closely related to Lingnan private gardens. Among them, the underlined variables are especially significant as they serve as key indicators for distinguishing between Jiangnan and Lingnan private gardens. In **Table 4**, the positive variables encompass characteristics common to both Jiangnan and Lingnan private gardens, while the negative variables specifically refer to the unique attributes of northern private gardens. According to the positive and negative variables in **Table 5**, the negative variables pertain to those of northern private gardens, and the underlined variables may represent unique variables of northern private gardens.

Table 3. List of positive and negative variables in Principal component 1

Positive variables	Water system, supplemented by rockeries; halls and corridors, supplemented by rockeries; *Ting shan* (the mountain picked in the courtyard in front of the hall); lotus hall; flower hall; four-sided hall; mandarin duck hall (the indoor partition divides the space into two equal sections); dwelling; platform; sacrificial architecture; platforms for water play; island; round pavilion; half pavilion; fan-shaped pavilion; stele pavilion; cave; inner and outer corridors; climbing corridor; winding corridors; gallery house; half corridor; archway; stone slab bridge; zigzag bridge; pavilion bridge; open hall; stone ornaments; *neng qiang fa qiang* (a structural approach that makes the eaves prominently uplifted at the wing butts); *shui qiang fa qiang* (this approach creates a unique visual effect through the upward curve of ridges and the straight edge of eaves); double eave roof; Chinese style tile; plain clay tube tiles; whitewashed wall; garden within a garden; Malus spectabilis pattern gate; French windows; hollowed-out windows; rows of decorative perforated windows; *Bubujin* (rectangular patterns formed by slats); lantern-shaped brocade; ice crack pattern; flower wall; louvered window walls; herringbone pavement; plant pattern pavement; *Malus spectabilis* pattern pavement; animal pattern pavement; ice crack pattern pavement design; hexagonal paving where hexagons serve as the basic units, is embedded with various materials such as pebbles and broken tiles; auspicious pattern pavement; Swastika pattern pavement; coin pattern pavement; tortoise shell brocade pavement; gravel path; stone pillar; stacked stone rockeries; earthen hill; yellow stone; stone wharf; scattered placement; symmetry placement; stone shores; streams; water brooks; wells; contrast between concealment and openness; *qu shui liu shang* (drinking water from a winding canal with one wine cup floating on it so as to wash away ominousness); *Yulania denudata*; *Pterocarya stenoptera*; *Magnolia grandiflora*; *Phragmites australis*; *Wisteria sinensis*; *Ulmus pumila*; *Acer palmatum*; *Cinnamomum camphora*; *Ginkgo biloba*; *Cupressus funebris*; *Musa basjoo*; *Acerpalmatum thunbf*; wintersweet; *Firmiana simplex*; willow; *Styphnolobium japonicum*; *Paeonia suffruticosa*; *Albizia julibrissin*; *Prunus mume*; *Punica granatum*; *Syringa oblata*; *Hydrangea macrophylla*; *Zelkova serrata*; *Triadica sebifera*; *Trachycarpus fortunei*; *Zanthoxylum bungeanum*; *Ligustrum lucidum*; *Hibiscus syriacus*; *Cercis chinensis*; *Michelia figo*; *Ilex cornuta*; *Buxus sinica*; *Acer genus plants*; *Nerium oleander*; Toona sinensis; *Rosa multiflora*; *Cerasus*; phoenix tree; *Morus alba*; *Prunus armeniaca; Diospyros kaki*; Malus spectabilis
Negative variables	Buildings and walls enclosing courtyards; theatrical stage; Islamic garden landscaping techniques; boat hall; bridge pavilion; *lian fang bo sha* (peripheral outlines of garden buildings in clusters and groups); practical front eaves corridor; watchtower; arch bridge; high-walls and narrow ventilated alleys; hanging gable roof; green door and window frames; brick carving; gilded paint; ceramic sculpture; gray sculpture; stained glass; clay sculptures; green-painted column; diamond-shaped doors; fruit and floral pattern; colored glass; arched window; oyster shell window; multicolored carved glass; blue brick wall; yellow painted wall; grayish-blue wall; colored railing; brick railing; granite paving; coral stone; stone wall; Ying stone (limestone from Yingde County in Guangdong Province); yellow stone; tree stone; shell decoration; geometric-shaped pool bank; fountains; spring, river, pond, waterfall, and sea combined scenic areas; animal patterns; marine culture patterns; *Sterculia nobilis Smith*'s seed; *Chrysanthemums; Camellia japonica*; *Rhapis excelsa*; *Tacca palmata*; *Hymenocallis littoralis*; sunflower family; *Cymbidium*; *Murraya exotica*; *Michelia alba*; *Litchi chinensis*; *Dimocarpus longan*; *Artocarpus heterophyllus*; *Magnolia grandiflora*; *Bauhinia variegata*; *Tabernaemontana divaricata*; *Ixora chinensis*; *Gardenia jasminoides*; *Rhaphiolepis indica*; *Jasminum sambac*; *Caesalpinia pulcherrima*; *Cycas revoluta*; *Hemerocallis fulva*; *Ficus microcarpa*; *Areca catechu*; *Averrhoa carambola*; *Plumeria rubra*; *Callistemon viminalis*; *Yulania denudata*; *Mangifera indica*; *Magnolia liliflora*; *Psidium guajava*; *Citrus maxima*.

Table 4. List of negative variables in Principal component 2

Negative variables	North-south axis; residential garden zoning; theatrical stage; architectural courtyard layout; Western gardening techniques; Western fountain sculptures; round pavilion; climbing corridor; practical eaves corridor; culture of the character "Fu"; hanging gable roofs; green glazed tiles; yellow glazed tiles; green window and door frames; brick carving; gilded paint; green-painted columns; *Bubujin* (rectangular patterns formed by slats); false windows; tiger-striped wall; bluish-gray wall; ice-cracked wall; screen wall; colored railing; auspicious pattern paving; pebble path; granite pavement; earthen hill; sundial; arranged planting; willow; *Styphnolobium japonicum*; *Chrysanthemum*; *Vitis vinifera*; *Syringaoblata lindl*; *Juglans regia*; *Malus spectabilis*; *Euonymus bungeanus; Cotinus coggy*gria

Principal component 4 reflects the dimensional differences in the internal types of Lingnan private gardens, providing a solid basis for exploring the distinctive elements among different Lingnan private gardens. In **Table 5**, the positive variables point to a set of characteristic variables for one type of Lingnan private garden, while the negative variables correspond to the unique attributes of a different kind of Lingnan private garden.

Table 5. List of positive and negative variables in Principal component 4 and their intersection with variables of Lingnan Private Gardens

Positive variables	Dwelling; stone boat; pavilion; sacrificial architecture; platforms for water play; island; hexagonal pavilion; bridge pavilion; cave; emperor's inscription tablet/monument/plaque; covered bridge; concepts of poetry and painting; deeper meanings; stone slab bridge; bridge corridor; open hall; pyramidal roof; green glazed tiles; green door and window frames; stained glass; garden within a garden; rows of decorative perforated window; turtle shell pattern; gable wall; cloud wall; louvered wall; colored railing; stone railing; stone wall; tree stone; stone wharf; scattered placement; specially placed; symmetry placement; stone shore; fountain; suppress scenery; added scenery; vista line; obstructive scenery; borrowed scenery; framed views; transitions between large and small spaces; contrast between solid and void spaces; animal patterns; *Eriobotrya japonica*; *Wisteria sinensis*; *Pinus*; *Musa basjoo*; *Chimonanthus praecox*; *Nymphaea tetragona*; *Sterculia nobilis Smith*'s seed; *Prunus persica*; *Plumeria rubra*; *Mangifera indica*; *Magnolia liliflora*; *Psidium guajava; Cit*rus maxima
Negative variables	Entrance hall; pavilion corridor; flat roof; whitewashed wall; arched window; plant pattern paving; *Malus spectabilis* pattern flooring; stacked stone rockery; *Chrysanthemum*; *Prunus persica*; *Parthenocissus tricuspidata*; *Tacca palmata*; *Litchi chinensis*; *Bauhinia variegata*; *Tabernaemontana divaricata*; *Gardenia jasminoides*; *Rhaphiolepis indica*; *Jasminum sambac*; *Caesalpinia pulcherrima*; *Hemerocallis fulva; Areca* catechu

5. Discussion

5.1. Comparison of differences among three types of private gardens

The most distinct differences among the three major private garden systems are concentrated in their unique layout concepts and architectural structure types. Specifically, Jiangnan gardens are characterized by the separation of residences and gardens. Notable examples, such as the Humble Administrator's Garden, Lingering Garden, and Lion Grove Garden, are cleverly arranged with halls and ponds at their core, surrounded by pavilions and towers, interconnected through winding paths and corridors. In contrast, Lingnan Garden often adopts a courtyard-style layout. For instance, Ke Garden employs the "peripheral outlines of garden buildings in clusters and groups" technique, enclosing the residence and garden into a closed courtyard. Qinghui Garden uses a clever division between buildings and walls to place scenery within individual courtyards, varying in size. Northern gardens, however, are marked by a distinct north-south axis and traditional *Si he yuan* (courtyard house) structure. During the Qing Dynasty, they were further influenced by Western garden concepts. For example, the garden of Beile Tao's residence emphasizes the relationship between the east and west axis, the introduction of arcs, and the composition tends toward geometric forms, contrasting sharply with the meandering and twisting layouts of Jiangnan gardens.

In the designed layouts of classical gardens, architecture is undoubtedly an indispensable and crucial design element. As shown in **Table 1**, the diversity of architectural structures has become a significant mark for visually distinguishing between Jiangnan and Lingnan gardens. Jiangnan private gardens are renowned for their wide variety of architectural types, characterized by lightweight forms and elegant colors. The eaves are cleverly designed using techniques such as *neng qiang fa qiang* (a structural approach that makes the eaves prominently uplifted at the wing butts), *shui qiang fa qiang* (an approach that creates a unique visual effect through the upward curve of ridges and the straight edge of eaves), particularly notable in their double-eave designs for pavilions and towers. In contrast, while both Northern and Lingnan private gardens also employ cornices, their degree of elevation is far less pronounced than that of Jiangnan gardens, and they mostly feature single-eave structures. Lingnan gardens have given rise to unique architectural types such as watchtowers, high-walls, narrow ventilated alleys, boat halls, and *lian fang bo sha* (peripheral outlines of garden buildings in clusters and groups), all adapted to their unique climate conditions characterized by high temperatures, heavy rainfall, humidity, and frequent typhoons. Although Northern gardens do not exhibit significant differences in architectural functions when compared to Jiangnan gardens, they present a distinctly different style in the private gardens of nobility and royalty. They utilize green or yellow glazed tiles and red or green frames and columns, resulting in bright and vivid colors that are rare in the private gardens of Jiangnan and Lingnan.

The differences in detailed design are also significant. Private gardens in Jiangnan excel at using bricks and stones to pave the ground, with pebbles meticulously arranged into herringbone patterns, ice crack patterns, and other auspicious designs. In contrast, the paving in the private gardens of Lingnan tends to be more regular, taking into account the rainy climate. Sometimes, a full paving design is used to promote drainage, with materials predominantly being brick or granite. The essence of decorative art in Lingnan Gardens lies in the "Three Carvings" and "Three Sculptures." Three Carvings refer to wood carving, brick carving, and stone carving, and the Three Sculptures encompass pottery sculpture, clay sculpture, and ash sculpture. For example, the "Hundred Birds Returning to Their Nest" depicted in the Ke Garden is carved by Hai Diteng, with the beauty of "Three Sculptures" observable in the ridge, the top part of a lintel, walls, flower beds, and other places. These decorative elements are relatively rare in gardens of Jiangnan and Northern China. In Northern private gardens, roads, platforms, and vacant areas are primarily made of bricks, with some paths paved with strip stones or gravel, even incorporating animal patterns, such as the camel pathway in Prince Gong's Mansion, thus sharing a similarity with Jiangnan gardens. However, the pathways relatively lack the meandering characteristics seen in Jiangnan gardens.

As an indispensable element, as shown in **Table 1** and **Table 2**, plants are not only essential components of garden design in the private gardens of Jiangnan but often become the focus of appreciation. For example, in the Humble Administrator's Garden, the Pavilion of Eighteen Datura Stramium features whitewashed walls as the backdrop, accompanied by lakes and rocks, reflections displayed in the clear water, with the solitary *Magnolia gradiflora* and *Ginkgo biloba*, the paired *Pinus*, and the clustered bamboos all emphasize the important role of plants in the private gardens of Jiangnan. Additionally, *Pterocarya stenoptera*, *Wisteria sinensis*, *Ulmus pumila*, *Acer palmatum*, *Musa basjoo*, and *Paeonia suffruticosa* are also common sights in Jiangnan gardens. The Lingnan region is renowned for its rich variety of plant species and distinctive regional characteristics, widely employing tree species that evoke the southern style, such as *Areca catechu* and *Arecales*. Due to the hot and rainy climate, shade and heat-resistant plants are highly favored, including *Ficus* plants and fruit trees like *Dimocarpus longan* and *Averrhoa carambola*, as well as vibrant and fragrant plants such as *Murraya exotica*, *Magnolia grandiflora*, and *Ixora chinensis*. These plants are not found in Jiangnan or northern gardens. Although northern gardens are limited by cold climates, they also exhibit unique characteristics in plant landscaping. Influenced by imperial thoughts and Western gardening culture, some areas adopt a formal, linear layout to enhance compositional effects, with trees such as *Sophora japonica*, *kapok*, *Juglans regia*, and *Ziziphus jujuba* occupying significant positions. In private gardens, shrubs like *Malus spectabilis* and *Syringa oblata* are predominant, alongside a keen interest in cultivating flowers like *Chrysanthemum* and vine plants such as *Vitis vinifera*.

The differences in geography and culture profoundly influence the style of garden art. The gardens of Jiangnan are often praised as "scholar's gardens." Although their owners reside in bustling cities, they harbor an endless yearning for the natural mountains and forests, integrating the poetic and artistic essence into their garden designs, thus imbuing the gardens with profound cultural connotations and aesthetic pursuits. In contrast, the gardens of Lingnan are deeply influenced by maritime culture. As seen in **Table 1**, this characteristic is particularly evident in Lingnan gardens, notably through the widespread use of boat halls, such as the boats in the

Ke Garden, the *Xiao jie lou* (The residence of an unmarried young lady from a wealthy family in Feudal era) in the Qinghui Garden, and the boat halls in Liang Garden, along with oyster shell windows made from shells, all of which express a deep affection for the maritime life of Lingnan. Furthermore, Lingnan private gardens draw on the essence of Islamic garden design, often incorporating geometric lines on the shores of ponds. In comparison, while maintaining the basic style of natural gardens, Northern gardens emphasize the axis due to the infiltration of imperial thought and Western garden concepts. For example, Beile Tao's Garden intentionally incorporates elements of European gardens, such as fountains and Western sculptures, showcasing a unique charm created by the fusion of Chinese and Western styles. Data from the charts also reveal that the use of the zigzag bridges and French windows as iconic elements in Jiangnan private gardens far exceeds that of the other two types of gardens.

5.2. Comparison of types within the three categories of private gardens

The scatter plot reveals that the ratings of the three private gardens in the Jiangnan region are highly close to each other. In contrast, the ratings of the three Northern gardens and the three Lingnan gardens are more dispersed, indicating a high level of similarity in the landscaping elements of Jiangnan gardens, with no obvious classification.

We find that the nature of these two groups is not distinct, and both incorporate diverse gardening elements. Based on the analysis of variables with factor loadings exceeding 0.7 in absolute value, the distinguishing features of the positive group include water-friendly platforms, rocky shores, and rocky islets, while the negative group has only one variable, flat roofs, which seems to point to the differences in the treatment of water bodies. Although both groups of gardens are dominated by geometric shorelines, Qinghui Garden and Liang Garden are more naturalistic in their localized details, exuding the flavor of private gardens in the south of the Yangtze River. However, given the limitations of the current observations and variables, the current study is not sufficient to fully define the exact differences between these two types of gardens, and future research needs to expand the scope of the data to dig deeper and clarify the differences between them.

In the analysis results of the fourth Principal component, the grouping of Lingnan Gardens is noteworthy. The Ke Garden stands out as an independent group, while the Qinghui Garden and Liang Garden are classified into another group. A deeper exploration of the positive and negative components reveals that the characteristics of these two groups are not entirely distinct, as they both encompass a diverse range of landscaping elements. Based on the analysis of variables with absolute factor loadings exceeding 0.7, the significant features of the positive group include platforms for water play, stone shores, and stone wharves, while the negative group only has the flat top as a variable. These differences seem to indicate variations in the treatment of water bodies. Although both groups of gardens primarily feature geometric shorelines, Qinghui Garden and Liang Garden appear more natural in their local details, showcasing the charm of Jiangnan's private gardens. However, given the current limitations of observation and variables, the existing research is insufficient to comprehensively define the exact differences between these two types of gardens. Future studies should expand the data scope to further explore and clarify their distinctions.

6. Conclusion

This study used principal component clustering analysis to obtain the analysis results of 9 classical private gardens in Northern, Jiangnan, and Lingnan gardens, revealing the differences and similarities between these three types of gardens. It is hoped that the gardening rules between these three types of gardens can be discovered, which will help explore the characteristics and differences of other types of gardens and provide new research ideas for targeted studies on the differences between different types of gardens in the future. In future research, we will further enrich the research elements and provide guarantees for the accuracy of the research results.

Disclosure statement

The authors declare no conflict of interest.

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Analysis of the Current Situation of Cost Management and Control of Highway Construction Projects

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Abstract: The highway engineering process is complex, coupled with a relatively long construction period, hence requires increased coordination between participating units to prevent economic disputes and efficiency losses. The main body of the construction project needs to strengthen the management and control of funds. In this regard, this paper analyzes the importance of cost management in highway projects by clarifying and analyzing the current cost management status quo problems and causes. The highway engineering cost control strategy and implementation methods are summarized to provide references for improving the quality of highway engineering.

Keywords: Highway engineering; Cost management; Management status; Cost control

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1. Introduction

Cost management is the key component of the construction management of engineering projects. The staff must consider the construction characteristics of engineering projects, the cost control issues for the overall deployment, and strengthen the problems of over-budget in advance to prevent and cope with the processing, all to ensure that the construction of engineering projects benefits from the loss of impact [1]. Highway engineering projects are large-scale and the risk of cost control faced is relatively large. To avoid the excessive loss of benefits, relevant personnel need to combine the construction characteristics of highway engineering projects, based on the whole life cycle perspective to strengthen the cost control of the various stages to effectively enhance the cost management of highway engineering projects.

2. Analysis of the importance of the implementation of highway project cost management

As construction management is the core of a construction project, the personnel involved must be based on the whole life cycle perspective of the construction project, and take the initiative from the investment decision, bidding, design, construction, completion, and other important stages to control the use of funds within the fluctuation range, that is, within the approved investment limit, to avoid over-budgeting and other problems that may affect the efficiency of the project [2]. Once the problem of over-budgeting occurs, the deviation must be corrected promptly. Through in-depth analysis of the specific causes, scientific and reasonable measures can be implemented to prevent adjustments, ensure the smooth realization of the investment objectives of the construction project, and ensure that all types of resources can be optimally configured to achieve the expected return on investment [3].

Based on the control principle, the project cost management needs to actively implement dynamic control of funds for the construction stages. During the control period, it is necessary to implement the control concept, focusing on the project feasibility study stage, preliminary design stage, project construction stage, and other important stages involved for detailed analysis and control. The project feasibility study report stage needs to be strengthened for the investment estimation of the problem of high attention, and the project construction stage needs to be strengthened for the project settlement problem, all to avoid the loss of benefits [4].

Overall, the standardization of highway project cost management can achieve the goal of optimizing benefits, through the early prevention of over-budgeting and related benefit losses to ensure that highway project cost management is always stable. In this regard, the relevant staff should strengthen cost management through integrated planning and timely prevention of cost risks.

3. Analysis of the current situation and causes of cost management of highway projects

The cost management concept is evolving backward with low management efficiency. However, it is still adopted by some, where it ignores the relevance of cost management in each construction stage, lacks awareness of the whole process of cost control, and does not adopt new methods and theories to transform and upgrade the traditional cost management system, which ultimately leads to the poor cost management efficiency and economic losses [5].

Cost personnel do not realize the relevance of contract management and cost management and lack attention to the details of contract management, resulting in a lack of basic support for cost management work and is prone to over-budgeting problems. Furthermore, the implementation of the basic content of cost management is not standardized, such as the estimation index and budget quota are not combined with the actual situation, thus being unable to provide the basis for subsequent cost management. There is also insufficient pre-construction investment control that could easily lead to over-budgeting problems. Lastly, the ability and quality of cost personnel need to be improved. Some practitioners have limited professional ability and lack attention to cost management details, resulting in the cost management level not meeting expectations.

4. Analysis of cost control strategies and implementation methods for highway projects

4.1. Technology-enabled cost control management and realize the whole life cycle cost control

By utilizing Building Information Modeling (BIM) technology, three-dimensional (3D) modeling and other modern information technology can be obtained on all types of engineering information to fully integrate it into modeling processing [6]. After a series of integrations, the BIM model can present the real highway project as a 3D model. Operators can use the simulation, synergy, virtualization, and other functional advantages of the

BIM model to create, simulate, and analyze the highway construction process, identify risk issues in advance, and strengthen the whole life cycle control of the project cost.

4.1.1. Pre-investment decision-making

Relying too much on experience to carry out investment estimation work is usually difficult to ensure the accuracy of the results, which is not conducive to promoting the smooth implementation of subsequent construction work. By relying on the BIM model database system, cost estimators can integrate the data information in the application system for in-depth comparison such as comparing and analyzing the market price of raw materials, machinery prices, and other data, to scientifically complete the research and analysis of estimation indicators. During this period, the cost personnel can also take advantage of the simulation function of the BIM model to accurately compare and analyze the different types of investment decision-making programs. The advantages and disadvantages of the different programs are then clarified in real time and the best investment decision-making program is selected for application [7].

4.1.2. Bidding stage

Due to the relatively large volume of highway engineering projects, coupled with the complicated construction process, it is easy to lose a significant number of items during the preparation stage. The creation of a BIM model allows for a comprehensive analysis of bidding projects. This process involves integrating the BIM model with pricing standards to carry out accurate and high-quality quotation calculations. Simultaneously, the BIM model can intuitively analyze and calculate the highway's monolithic structure and the overall number of projects to prevent the problem of imprecise data calculation, which may trigger a series of negative impacts such as over-budget [8].

4.1.3. Design link stage

Created using the BIM model, this approach helps cost personnel obtain basic data information for highway engineering in advance, enabling scientific optimization work following standard design limits. During the design optimization period, the cost of each project unit can be accurately checked and analyzed, combined with the analysis of the overall design program for overall optimization, to improve the feasibility of the design. Additionally, the optimization of the preparation of construction drawings can take advantage of the synergistic function of the BIM model to promote the cooperation of various professional work, make improvements on a unified platform, highly implement the budgeting content of the construction drawings, and reduce the possibility of subsequent design changes.

4.1.4. Construction stage

The visualization function of the BIM model can be used to simulate and analyze the process involved in each construction stage of the project in advance and identify the possible risks. During this period, the designers and constructors should combine the data resources acquired through the BIM model to complete the data and information sharing and collaborative communication and conduct appropriate discussions and modifications for the construction program to prevent design changes during formal construction.

During the formal construction stage, the cost staff can use the real-time statistical analysis function of the BIM model to comprehensively analyze the consumption of raw materials and the use of equipment, and reasonably allocate the use of resources to prevent wastage and other issues that may affect construction costs. It is worth noting that if the construction phase encounters design changes, in addition to the need for timely communication with the design team, it is also necessary to update the data in the BIM model, so as not to affect the progress of subsequent construction [9].

4.1.5. Completion stage

The completion stage using BIM modeling can be integrated to obtain data during the construction phase and other relevant information. By having comprehensive access to cost information and related data, the accuracy of the completion of the project can be guaranteed. Concurrently, the cost audit period can also be accessed from the BIM model database, and through automatic comparison and analysis, relevant personnel can effectively master cost control.

4.2. Strengthen the comprehensive control of the contract implementation process and improve the level of cost control

Highway project capital investment is a large and relatively long construction process, where the construction phase needs to revolve around the contract terms and conditions of the agreed content to prevent delays or economic losses. Hence, the implementation of a contract management for ensuring highway engineering economic efficiency and quality enhancement is crucial. Most importantly, the cost control of the construction process is a key component. Therefore, after the completion of the contract, the contract management personnel need to facilitate the whole process of supervision and management for the implementation of the contract following the dynamic monitoring method. Once any party violates the contract, relevant personnel are responsible for correcting any wrongdoings to avoid affecting the realization of the target cost objectives [10].

Managers should also apply the implementation of contracts for the whole process of supervision. For example, for the construction phase, meeting minutes and other important information must be collected and organized. It should be noted that the project site can be easily influenced by many factors and design changes. For design changes, managers need to reasonably adjust the project price according to the contract provisions. If the changes required exceed the original budget, a requote is needed, followed by a series of rigorous reviews, before full implementation.

Furthermore, the contract management should ensure that the project settlement method is scientific and feasible to confirm the accuracy, focusing on the construction phase by carefully reviewing problems and timely checking for defects and omissions. This is to ensure the authenticity and reliability of the settlement results. Throughout the process, a special pricing rectification group can be set up to correct and deal with unreasonable pricing terms or incomplete content and prevent the two responsible parties from economic disputes.

4.3. Attention to cost management foundation work to strengthen the quality of fine cost control

The responsibility of project cost management is to strengthen the quality of cost control measures. In the management period, the staff must understand the basic content of project cost management to be implemented. On the one hand, the actual situation of the highway project should be considered when establishing the estimation index and budget quota. On the other hand, the cost personnel can use information technology to establish the material price and regularly release relevant cost information to facilitate cost control. It should be noted that the cost personnel need to fully integrate and objectively analyze the historical cost information to provide basic data for cost management.

4.4. Strengthen project pre-construction investment control and reduce over-budget problems

Implementation of the pre-construction investment control work is crucial to reduce over-budget problems. In practice, the staff needs to focus on the review of construction drawings and optimize them. Before the formal construction, the construction drawings can help deal with unreasonable problems for timely rectification to avoid subsequent design changes and other impacts that may affect cost. During the construction bidding stage, we must select a good credit bidding agency to complete a series of control management work such as the preparation of bidding documents.

Bidding documents can be regarded as an important basis for highway engineering project construction bids and also in guiding bidding unit decisions, bearing significant impact. Moreover, managers must analyze the construction organization design program throughout the entire process to determine its feasibility. It should be noted that during the whole process, the supervision unit is responsible for facilitating supervision and management functions, strengthening the quality of the project construction, and the progress of strict control, to ensure that all costs are controlled within the expected range.

4.5. Improve the professional ability of practitioners, and steadily improve the level of cost control and management

Many people are involved in the highway construction project. Coupled with the high degree of complexity of the construction technology process, it results in higher project cost management difficulty than conventional projects. To strengthen the centralized control of the overall cost of highway projects and reduce the problem of efficiency losses, cost practitioners must strive to improve their professionalism. Among them, cost personnel need to establish a standardized cost management system from the project feasibility study stage to the completion stage. Strengthening the communication and coordination with other departments involved in the cost management promptly can control the cost of construction within a reasonable range. Simultaneously, the staff must have the theoretical and practical ability to skillfully apply professional knowledge to complete all kinds of cost control work. During the control period, the cost personnel can combine the content of the construction contract terms, construction changes, and many more to accurately account for the amount of work, timely detection of errors, and strengthen the control, to avoid the problem of efficiency losses.

5. Conclusion

The highway project cost management needs to adapt from the traditional sloppy management mode by adhering to the new concept and adopting new technology to establish high-quality cost management work. This is to ensure the cost management of highway project benefits is not impacted. Concurrently, the relevant personnel engaged in cost management must strengthen the individual cost control consciousness and strictly follow the contract content of cost control points to prevent over-budget and other economic risks. The staff must also establish the correct cost management behaviors, combined with experience and lessons learned to make up for any shortcomings. It is better to expand the staff's knowledge and enrich their theoretical and practical experience, all of which can better help smoothen the project cost management work to carry out high-quality construction work.

Disclosure statement

The author declares no conflict of interest.

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Research on the Dual Carbon Talent Training Model for the Construction Engineering Technology Major in Higher Vocational Education

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Abstract: Against the backdrop of global climate change and China's "dual carbon" goals, the green transformation of the construction industry is imperative, and completing the transformation requires many dual carbon talents to support it. This article focuses on the construction engineering technology major in higher vocational education. It explores in depth the specific requirements for construction engineering technology talents in terms of professional knowledge, vocational skills, and literacy under the dual carbon mode. Based on this, corresponding dual carbon talent training courses are proposed, aiming to provide theoretical support and practical guidance for cultivating high-quality dual carbon talents that meet the needs of the new era.

Keywords: Vocational education; Construction engineering technology; Dual carbon talents; Training mode

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1. Introduction

With the increasingly severe issue of global climate change, reducing carbon emissions has become a global consensus. China has proposed the "dual carbon" goal of "peak carbon emissions and carbon neutrality," and the construction industry, as an important sector of carbon emissions, is facing enormous pressure and transformation challenges [1]. In this context, cultivating construction engineering technical talents who can adapt to the dual carbon goals has become an important task of higher vocational education. Exploring effective models for cultivating dual carbon talents in the construction engineering technology major of higher vocational education, optimizing the curriculum system, improving teaching methods, and strengthening practical teaching to enhance the quality of talent cultivation, will provide strong talent support for the green and low-carbon development of the construction industry [2].

2. Specific requirements for construction engineering technical talents under the dual carbon background

2.1. Professional knowledge requirements

Under the trend led by the dual carbon target, the professional knowledge required for vocational construction engineering technical talents presents multidimensional and comprehensive characteristics. Firstly, it is necessary to have a solid grasp of architectural physics knowledge and clarify the principles of heat transfer, lighting, ventilation, etc., to optimize the energy utilization efficiency of buildings. Secondly, it is necessary to have a deep understanding of green building design concepts, including natural lighting and shading design, passive energy-saving strategies, etc., to integrate low-carbon thinking into the design stage. Furthermore, familiarity with the characteristics and applications of various low-carbon and environmentally friendly building materials, such as high-performance insulation materials, recyclable building materials, etc., provides a scientific basis for material selection. Simultaneously, mastering the integration and utilization of renewable energy, energy storage and management technologies, etc., to achieve self-sufficiency and efficient allocation of building energy. Additionally, one should be proficient in the calculation and evaluation methods of building carbon emissions, be able to accurately quantify the carbon emissions throughout the entire life cycle of buildings, and develop emission reduction plans based on this. Moreover, a clear understanding of building intelligent control technology is required to achieve precise control of building equipment and reduce energy consumption through intelligent systems. Finally, it is important to update relevant policies, regulations, and industry standards to ensure that construction projects achieve low-carbon emissions reduction to the greatest extent possible while complying with regulations [3].

2.2. Skill requirements

Under the dual carbon background, vocational construction engineering technical talents need to possess a series of key skills as follows.

(1) Possess precise skills in calculating and analyzing building energy consumption, able to use professional software and methods to conduct detailed evaluations of the energy usage status of various buildings, and accurately identify energy-saving potential areas.

(2) Master advanced green building construction technology and process management skills, be able to plan the construction sequence reasonably, and strictly control resource consumption and waste discharge in the construction process.

(3) Possess practical skills in using new low-carbon building materials, familiar with material characteristics and construction points, and ensure that the building achieves low-carbon environmental protection in the material use process.

(4) Master the monitoring and data processing skills of building carbon emissions, be able to use professional instruments and tools to collect carbon emission data, and conduct effective analysis and reporting.

(5) Possess Building Information Modeling (BIM) based carbon management skills for the entire lifecycle of buildings, utilizing BIM models to simulate and optimize carbon emissions from design, from construction to operation.

(6) Possess innovative thinking and solution optimization skills, able to propose innovative solutions and optimization plans for carbon reduction challenges in construction projects [4].

2.3. Literacy requirements

Under the trend of dual carbon background, vocational construction engineering technical talents need to possess various qualities, such as strong environmental awareness and social responsibility, and actively practice the dual carbon concept in their work. Capable of innovative thinking and teamwork as well as able to solve complex engineering problems in the context of dual carbon. Having the ability to continuously learn, constantly update knowledge and skills, and adapt to the development and changes of the industry.

3. Curriculum design for dual carbon talent training

Talent training courses are set up based on the specific requirements for the knowledge, skills, and literacy of construction engineering technical talents in the context of dual carbon. The curriculum is divided into four categories: basic courses, professional core courses, practical courses, and extended courses. To lay a solid theoretical foundation for students majoring in Construction Engineering Technology in vocational colleges under the dual carbon background through the study of basic courses. Professional core courses help cultivate students' professional abilities in energy conservation and emission reduction in construction engineering technology under the dual carbon background. The practical course will help students better apply theoretical knowledge to practice and enhance their ability to solve construction engineering technical problems in the context of dual carbon. Expanding courses help broaden students' horizons and enhance their comprehensive literacy and innovation abilities in the dual carbon field. The specific course offerings are shown in **Table 1**.

Table 1. Curriculum design for dual carbon talent training in construction engineering technology

Course category	Course name	Course content
Basic courses	Principles and Technologies of Building Energy Efficiency	Introduce the basic principles, energy-saving strategies, and common energy-saving techniques for building energy efficiency
	Introduction to Green Building	Enable students to understand the concept, design principles, and evaluation criteria of green buildings
	Application of Renewable Energy in Buildings	Teach the principles and methods of using renewable energy sources such as solar, wind, and geothermal energy in buildings
	Built Environment and Carbon Emissions	Analyze the impact of the built environment on carbon emissions, and how to reduce carbon emissions by optimizing the environment
	Low Carbon Building Materials	Study the characteristics, production processes, and application scope of various low-carbon and environmentally friendly building materials.
	Building Informatization and Carbon Management	Explain how to use information technology such as Building Information Modeling (BIM) to manage and control building carbon emissions
	Building Regulations and Dual Carbon Policy	Familiarize students with building regulations and policies related to dual carbon goals, ensuring that construction projects comply with legal and policy requirements
Professional core courses	Green Construction Technology and Management	Covers specific technologies, processes, and management methods for green construction to reduce energy consumption and carbon emissions during the construction process
	Building Energy Systems and Energy Conservation Control	Explain the composition and operating principles of building energy systems, as well as strategies and technologies for energy conservation control
	Cost Management of Construction Projects under the Dual Carbon Target	Exploring how to estimate, budget, and control construction project costs under the dual carbon background, considering the costs and benefits of energy-saving and emission-reduction measures
	Assessment and Monitoring of Building Carbon Emissions	To enable students to master the assessment methods and monitoring techniques for building carbon emissions, and to accurately calculate and monitor the carbon emissions throughout the entire life cycle of buildings
	Application of BIM Technology in Dual Carbon Buildings	This article focuses on the application of BIM technology in the planning, design, construction, and operation stages of dual carbon buildings to improve energy efficiency and reduce carbon emissions
	Low Carbon Building Equipment Engineering	Teach the selection, installation, operation, and maintenance of various equipment in low-carbon buildings to ensure efficient and energy-saving operation of the equipment

Table 1 (Continued)

Course category	Course name	Course content
Practical courses	Low Carbon Building Materials Experiment and Application	Students personally conduct performance testing experiments on low carbon building materials and apply them to the production of actual building models or components.
	Green Construction Technology Training	Students participate in the operation of green construction technology in simulated or actual construction sites, such as the installation of energy-saving equipment and the classification and treatment of construction waste
	Practice of Debugging and Optimizing Building Energy Systems	Debugging and optimizing building energy systems, and mastering methods to improve energy utilization efficiency through practical operations
	Internship in Building Carbon Emission Monitoring and Data Analysis	Students participate in the carbon emission monitoring work of actual building projects, collect data, analyze it, and propose emission reduction suggestions
	BIM Dual Carbon Building Modeling and Simulation Practice	Using BIM software to create dual carbon building models, conduct energy consumption simulation and carbon emission analysis, and optimize design schemes
	Comprehensive Practice of Low Carbon Building Projects	Students are divided into groups to complete a low carbon building project, including simulation of the planning, design, construction, and operation stages, and apply their learned knowledge and skills comprehensively.
	Case Analysis and Practice of Construction Projects under the Dual Carbon Policy	Conduct case analysis on actual construction projects to study their response strategies and effects under the dual carbon policy.
Expanding courses	Carbon Trading and Construction Market	Introduce the mechanism and rules of carbon trading, as well as its application and impact on the construction market
	Building Feng Shui and Low Carbon Environment Creation	Exploring how to combine the principles of building Feng Shui to create a low carbon and comfortable building environment.
	Intelligent Buildings and Dual Carbon Integration	It discusses how intelligent building technology can be integrated with dual carbon goals to achieve more efficient energy management and emissions reduction
	Architectural Culture and Low Carbon Lifestyle	From the perspective of architectural culture, guide students to think about how to promote a low carbon lifestyle
	Management of Construction Enterprises under the Dual Carbon Background	Explain the management strategies and development directions of construction enterprises under the dual carbon target
	Architectural Art and Energy Conservation and Emission Reduction	Analyze the relationship between architectural art and energy conservation and emission reduction, and cultivate students' aesthetic and environmental awareness
	New Energy Vehicles and Building Facilities Support	Research on the planning and design of charging, parking, and other supporting facilities for new energy vehicles in building facilities

4. Teaching methods and practices for cultivating dual carbon talents

4.1. Reform of teaching methods

The cultivation of dual carbon talents is an important guarantee for achieving China's dual carbon goals, and the reform of teaching methods is the key to improving the quality of dual carbon talent cultivation. Project-driven teaching methods can be adopted, using actual construction projects as carriers to enable students to master dual carbon-related knowledge and skills in the process of completing projects. Simultaneously, using the case study teaching method, by analyzing successful green building cases locally and internationally, students' innovative thinking is stimulated [5].

4.2. Practical teaching session

Practical teaching not only helps students transform theoretical knowledge into practical application abilities but also enables them to gain a deeper understanding of practical problems and workflow in the dual carbon field, cultivating their ability to solve complex problems. In terms of practical teaching, it is necessary to strengthen the construction of on-campus training bases, equip them with advanced experimental equipment and simulation software, and provide students with a good practical environment. Concurrently, establish close cooperative relationships with enterprises, arrange for students to intern at enterprises, and participate in actual dual carbon engineering projects.

4.3. Construction of teaching staff

In the cultivation of dual carbon talents, the teaching staff plays a key leading and guiding role. In the process of building the teaching staff, teachers can be encouraged to participate in dual carbon-related training and academic exchange activities to improve their professional level. At the same time, we will introduce experts in the dual carbon field with rich practical experience to enrich the teaching staff.

5. Conclusion

The cultivation of dual carbon talents in the construction engineering technology major of vocational colleges is an inevitable requirement to adapt to the green development of the construction industry. By clarifying the specific requirements for talents under the dual carbon model, setting up a reasonable curriculum system, reforming teaching methods, and strengthening practical teaching, we can cultivate dual carbon talents with solid professional knowledge, proficient skills, good qualities, and contribute to the sustainable development of the construction industry.

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Disclosure statement

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Development of Sustainable Urban-Rural Integration: Dongtan Case Study

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Abstract: The environmental impact issues, such as global warming and expansion of the urban zone, seem more serious and have become the biggest defining challenges of the 21st century. Climate change can lead to water shortages, desertification, land degradation, air pollution, rising sea levels, accelerated deforestation, and exacerbated economic pressures. Global urban growth greatly impacts changes in sociability, humanity, and the environment of the Earth. The human presence, especially in cities, seriously affects resource use and waste disposal, and they are consuming natural resources faster than the planet can sustain during urbanization, changing how people live. China, with a population of 1.3 billion, has seen tens of millions of people living in the countryside migrate to cities, especially megacities, since the 1980s. As a result of its decision to industrialize and urbanize to boost the economy, China has become the world's second-largest consumer of energy. In recent years, China's government has quickly recognized the lessons of "limits to growth" and has taken action by initiating the construction process in Dongtan, Shanghai, China. They are making efforts to build urban-rural integration communities to promote sustainable development. Based on a literature review focusing on Dongtan, research questions are raised according to the research objective: (1) What are the challenges of sustainable development in urban-rural integration? (2) What practices has Dongtan implemented for sustainable development, or how is sustainable development being applied to Dongtan? (3) What are the social, political, environmental, and economic concerns regarding the sustainable development of Dongtan? The sustainable urban-rural integration concerns the ecological, economic, environmental, and psychological aspects of urban-rural integration design and management. The overall objective is to promote sustainable development in economic, social, ecological, and spatial dimensions. It will be a liveable, complete community that makes economic, environmental, and social sense locally while also contributing to national and global sustainable development. It will serve as a compelling model for how to build sustainable urban-rural integration worldwide.

Keywords: Environmental impact; Urbanization; Sustainable urban-rural integration; Sustainable development; Dongtan

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1. Introduction

Many changes and challenges are taking place in the 21st century. Globalization is among the greatest trends of the new century, leading to the development of some global cities that possess global functions in society, politics, culture, and economics. Although cities and countries are poised to integrate into the global system, they face growing dangers from rapid financial and economic changes, risking the ruin of their healthy economic infrastructure and causing the loss of their specific cultures. Another significant problem is the environmental impact, such as global warming (see **Figure 1** to **Figure 4**) and urban expansion. These issues seem more serious and have become the biggest defining challenges of the 21st century, as cities expand in size, consuming more energy and leading to the decline of forest and agricultural land usability. Big countries with mega and modern cities bear more responsibility for fossil fuel combustion (see **Figure 5**). They are critical factors in causing climate change and eventually become its victims.

Figure 1. Global average near-surface temperatures (NASA's Goddard Institute for Space Studies)

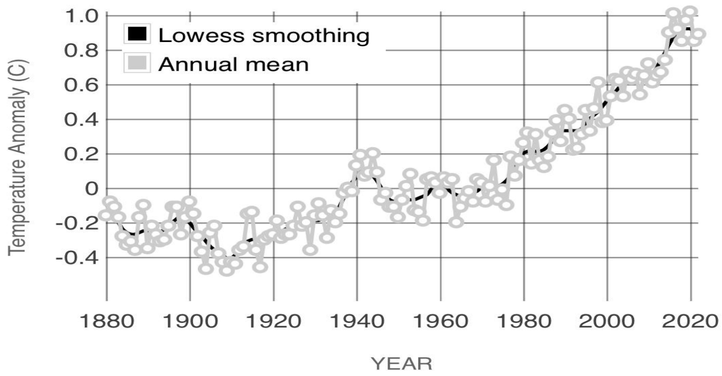


Figure 2. Global emissions of greenhouse gases come from a wide range of sources (World Resources Institute) Note: Chart shows the source of all greenhouse gases in carbon dioxide CO_2 equivalent. The unlabelled segments are industrial processes (purple) and waste (olive)

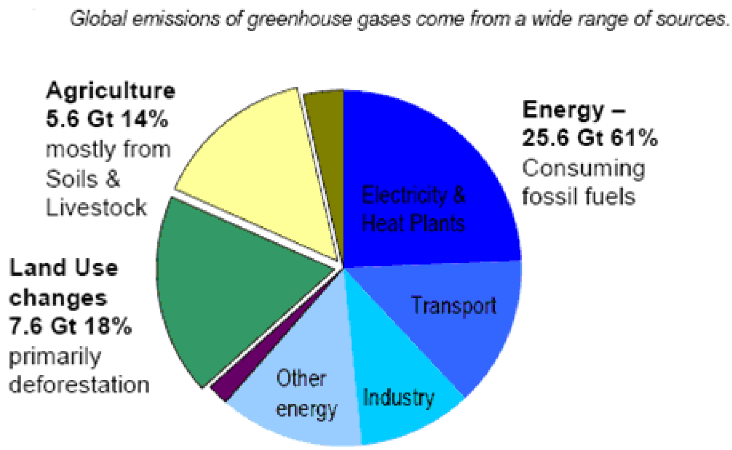
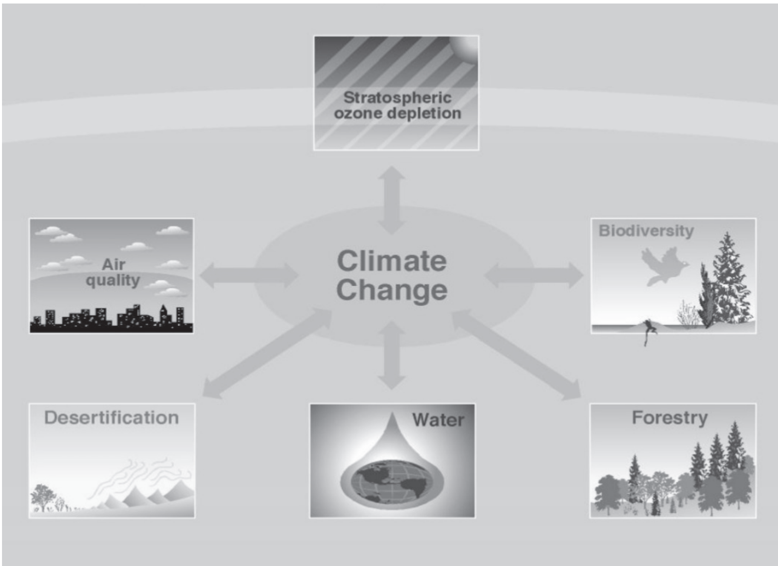


Figure 3. Climate change and the environment (Intergovernmental Panel on Climate Change, IPCC Synthesis Report)



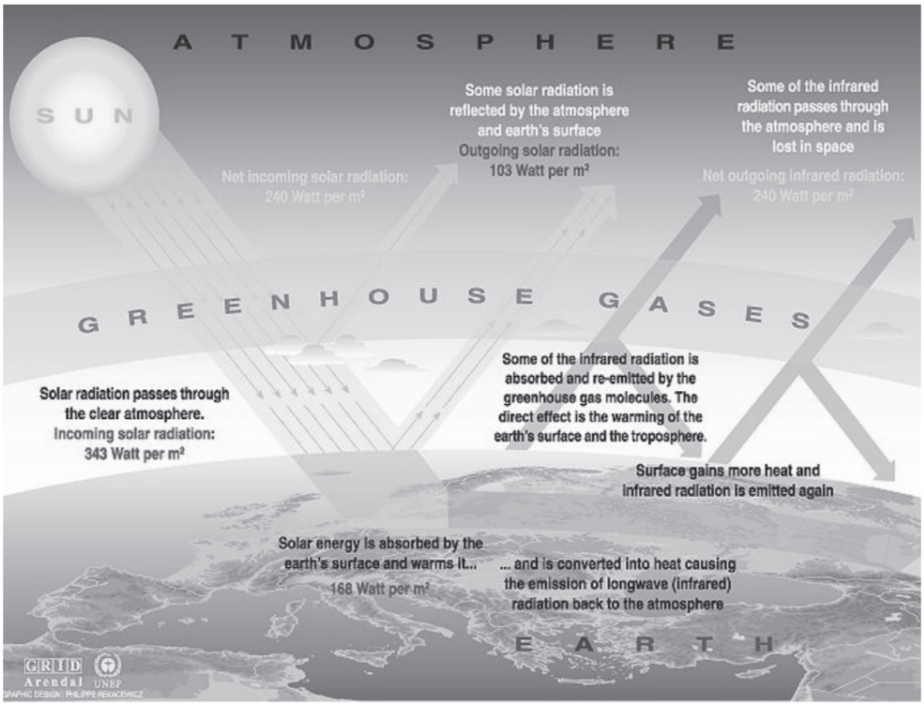


Figure 4. Greenhouse gas effect (Intergovernmental Panel on Climate Change, IPCC Synthesis Report)

Global urban growth has a significant impact on the changes in social dynamics, humanity, and the environment of the Earth. Megacities are the largest, most complex man-made structures, typically housing ten million or more people. They dominate the economies of countries and serve as central hubs for transportation and communication systems.

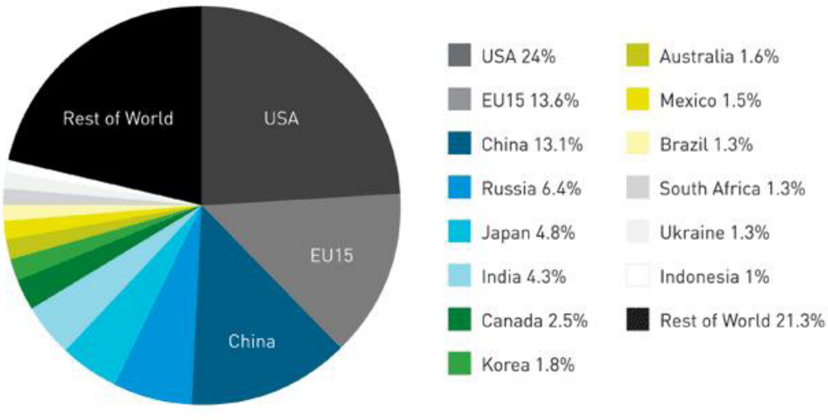


Figure 5. Shares of global energy-based carbon dioxide (CO_2) emissions, 2001 (Energy Future, Australian Government)

Unsustainable urbanization poses a threat to long-term security. As a matter of great urgency, we must recognize the need to integrate cities and countryside and remodel urban production, consumption, and transportation systems through recycling, remanufacturing waste materials, and composting organic materials. This new model, often referred to as zero-carbon, is essential.

Developing urban-rural integration faces the greatest growth challenges of the new century. To modify the structure of urban-rural integration to meet the significant needs of reducing their ecological footprint and improving energy efficiency, people need to be more aware of the need to protect the rural environment, prevent pollution, decrease deforestation, and make the land usable. Additionally, efforts must be made to lower carbon emissions to adapt to climate change. Sustainable urban-rural integration should have significant competitive advantages and be developed with well-planned, designed, and managed methods that are compatible with the earth and rural environments, providing the natural resources and energy on which we depend to live. In the process of developing urban-rural integration, local governments are in a position to play a critical role in advancing reliable, affordable, and environmentally sustainable cities.

Although China has a splendid civilization spanning almost 5,000 years and has built many spectacular cities such as Beijing and Nanjing dating back many centuries, with a large population, the main support for the people's livelihood was the villages and the farmers before China opened its doors to foreign trade and emphasized efforts on rapid economic development and attracting investment from the West.

Like many countries around the world, China is becoming increasingly urbanized following the decision to industrialize and boost the economy. With a population of 1.3 billion, tens of millions of people living in the countryside have migrated to cities in search of job opportunities, especially in mega-cities, since the 1980s. As a result of this migration and expansion, cities are experiencing greater urbanization, leading to issues such as increased energy consumption and serious pollution.

China has become the world's second-largest consumer of energy, following the United States of America (USA). There are many distressing scenarios, such as urban sewage, polluted air replacing the bright sky and clear air, industrial chemicals poisoning rivers and lakes, and the widespread construction of coal-fired power stations causing significant environmental problems. Even carbon oxide emissions are poised to catch up with those of the USA. The current energy-wasting, resource-intensive way of living cannot continue.

In recent years, since President Xi Jinping came into power, China has raised more concerns about the environment. The government has begun to realize the lessons of "limits to growth" more quickly and has taken steps to tackle man-made environmental problems. It has launched policies on "harmony between humanity and nature" and "building a conservation-oriented and environment-friendly" approach based on the concept of sustainable development. The government has emphasized that economic development must consider its impact on the environment and society. Actions have been taken, such as in Dongtan, to build a good example of sustainable urban-rural integration. These efforts aim to prevent energy shortages and maintain the current growth rate.

Dongtan is invested by the Shanghai Industrial Investment Corporation (SIIC). It is built on Chongming Island in the Yangtze River Delta and covers an area three-quarters the size of Manhattan Island, totaling 86 km^2. Dongtan is a local project with a global perspective. It is designed to be a beautiful and sustainable city with a minimal ecological footprint. This design aims to attract a range of commercial and leisure investments, ensuring that China plays a critical role in the emergence of a world with ecologically and economically sustainable human settlements.

2. Materials and methods

2.1. Understanding sustainability and sustainable development

The principles of sustainable development combine concern for the quality of life, social, economic, and human dimensions, as well as a long-term view regarding the health and integrity of the environment and future generations. It encompasses broader concepts compared to mere environmental protection. Sustainable development emphasizes that further development should only occur within the limits of natural system capacity, as exceeding these limits could pose dangers and harm human livelihoods (see **Figure 6** and **Figure 7**). There are five principles with respect to sustainable development (see **Figure 8**).

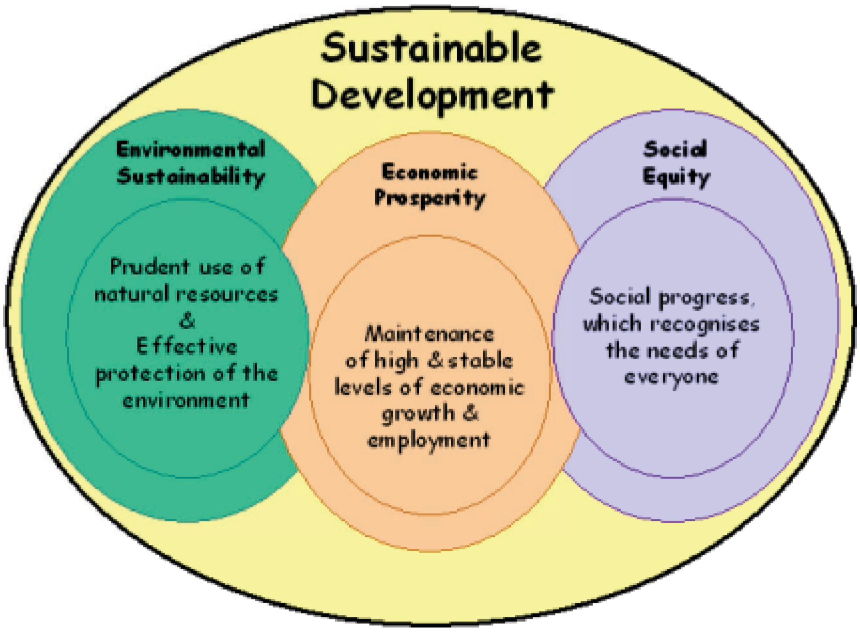


Figure 6. Impacts on sustainable development (Cornwall Community Strategy)

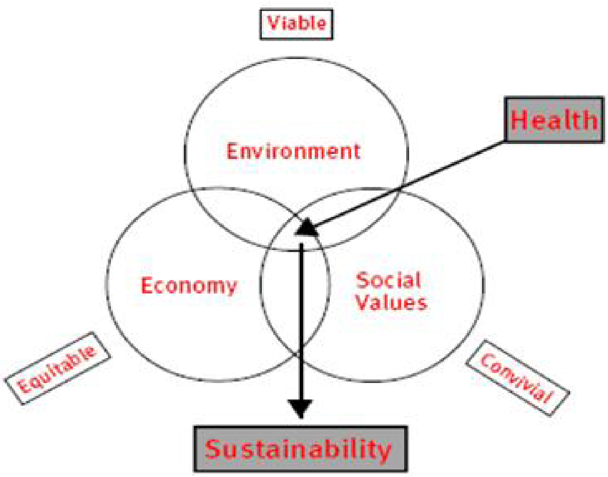


Figure 7. The conceptual model of sustainable development

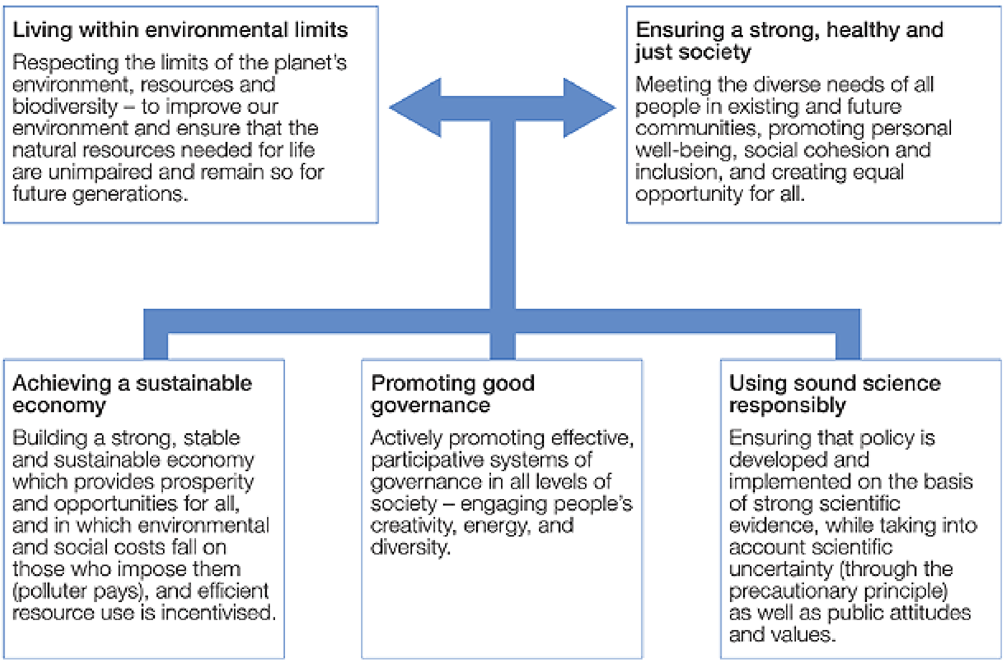


Figure 8. Four principles with respect to sustainable development (WHO Regional Office)

2.2. Sustainable development of urban-rural integration

2.2.1. Global trends in economics, demographics, and urbanization

With the development of the global economy, the impact of urban and rural areas on global systems is increasingly recognized. Cities and towns are affected by circumstances where strategies and decisions are often made far beyond their own borders. Understanding global and regional economic, social, environmental, and cultural trends is crucial for comprehending urbanization and other population distribution trends over the last two decades [1]. However, a significant challenge arises as natural resources decline while cities and towns worldwide face daunting environmental challenges on a global scale. The main characteristics of the globalization impact on economic and social transformation are as follows:

(1)Trade liberalization and structural reform

(2)Decline of manufacturing as the core economy

(3)Rise of electronic and information services

(4)Services becoming tradable

(5)Less capital-intensive compared to heavy industries

(6)Shift from old physical master planning to new strategic approaches

The world's population is predicted to increase from 6.5 billion to 9 billion by the middle of the 21st century. In less than twenty years, more than half of the developing world's population will be urban, with a fast-growing number of mega-cities, especially in developing countries (**see Figure 9** and **Figure 10**). With the rapid growth of the population, the global urban trend significantly affects economic, social, environmental, and political aspects worldwide. Some problems have emerged and are becoming increasingly serious, such as environmental deterioration, and lack of provision for piped water, sanitation, sewerage, roads, schools, and health centers. By 2035, urbanization is projected to cause a loss of 25% of agricultural land in China.

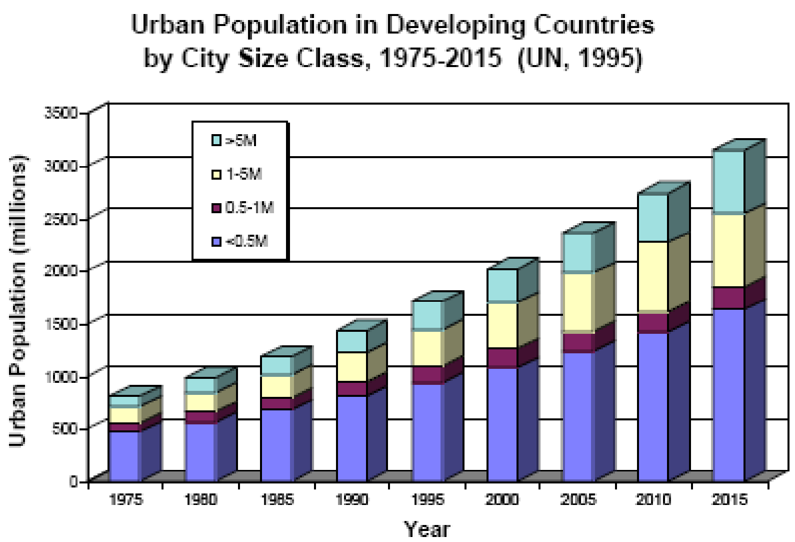


Figure 9. Urban population in developing countries by city size class, 1975 to 2015 (UN, 1995)

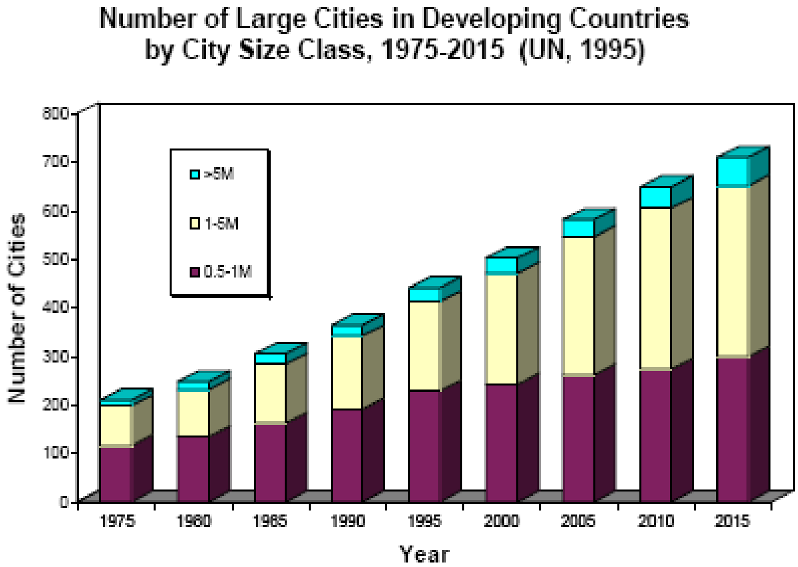


Figure 10. Number of large cities in developing countries by city size class, 1975 to 2015 (UN, 1995)

Like many other countries globally, China's cities face common problems during urban development. In fact, China has become one of the most urbanized countries in the world, with the largest population residing in cities and the highest number of mega-cities among nations. Furthermore, China ranks among the world's highest consumers of energy and water resources and is a significant generator of commercial and industrial waste.

2.2.2. The sustainable urban-rural integration policy design

Integrating policies at high levels aims to shift from sectional approaches to inter-sectional collaboration, promoting sustainability. Additionally, specific policies integrating rural land-use planning and practical project management ensure the utilization of natural resources within environmental capacity boundaries. Key strategies to support these goals include the following.

(1)Utilize tools and technologies to achieve a sustainable society by balancing and integrating various requirements and interests, advancing sustainable urban-rural integration planning.

(2)Utilize technology to manage flows such as water, energy, materials, and waste, aiming to enhance management effectiveness and efficiency to achieve sustainable resource use based on sustainable development principles.

(3)Implement physical approaches and economic instruments with local and regional legislation to manage environmental quality and amenity.

(4)Apply facilitative management techniques and best practices, including environmental and health impact assessments, environmental accounting, eco-auditing, green procurement, and economic instruments.

(5)Set sustainability targets as a powerful method to focus attention on critical challenges and provide a timed framework for action.

2.2.3. Sustainable urban-rural integration

2.2.3.1. What is the "Sustainable Urban-rural Integration?"

The "Sustainable Urban-Rural Integration" is a Swedish initiative with a holistic concept for the sustainable development of cities and rural areas. The concept of Sustainable City was developed by SWECO for the 2002

World Summit on Sustainable Development in Johannesburg, on behalf of the Swedish Government through the Ministry for Foreign Affairs, the Ministry of the Environment, and the Swedish environmental technology industry, facilitated by the Swedish Trade Council [2].

Within the growing economy of a developing country, “sustainable” means the ability to control spatially sprawling suburbanization. The definition of sustainable urban-rural integration is generally understood to encompass the ecological, economic, environmental, and psychological aspects of designing and managing urban and rural areas. The overall objective is to promote sustainable development across economic, social, ecological, and spatial dimensions within both urban and rural contexts (see **Figure 11**).

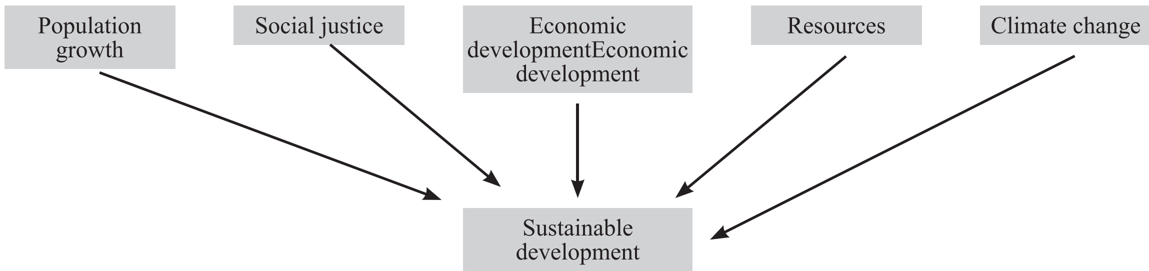


Figure 11. Impacts on sustainable urban-rural integration

The key points of sustainable urban-rural integration are presented as follows.

(1)Green architecture, sustainable planning, and enhancement of the city and rural environment

(2)Energy efficiency and renewable energy: an urban-rural response to climate change

(3)Sustainable transport systems

(4)Environmental psychology for sustainable urban-rural development

(5)Urban-rural biodiversity and resilience of urban-rural ecosystems

(6)Ecologically friendly social and economic benefits

(7)Urban-rural limits and risk analysis: material flows and ecological footprint

2.2.4. Design and develop sustainable urban-rural integration

2.2.4.1. Sustainability strategy

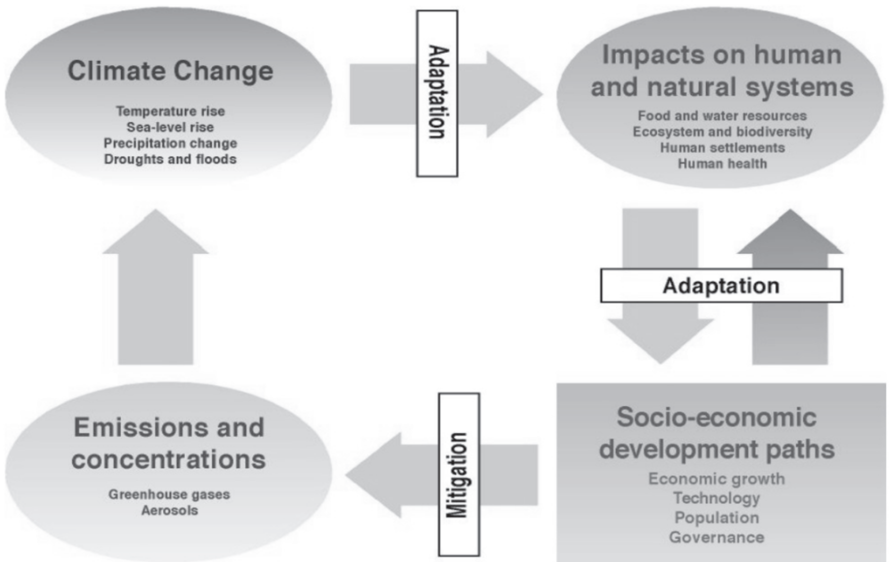


Figure 12. Climate change integrated framework (Intergovernmental Panel on Climate Change, IPCC Synthesis Report)

2.4.4.2. Plan and design sustainable urban-rural integration

Figure 13 shows the details of the elements of designing sustainable cities.

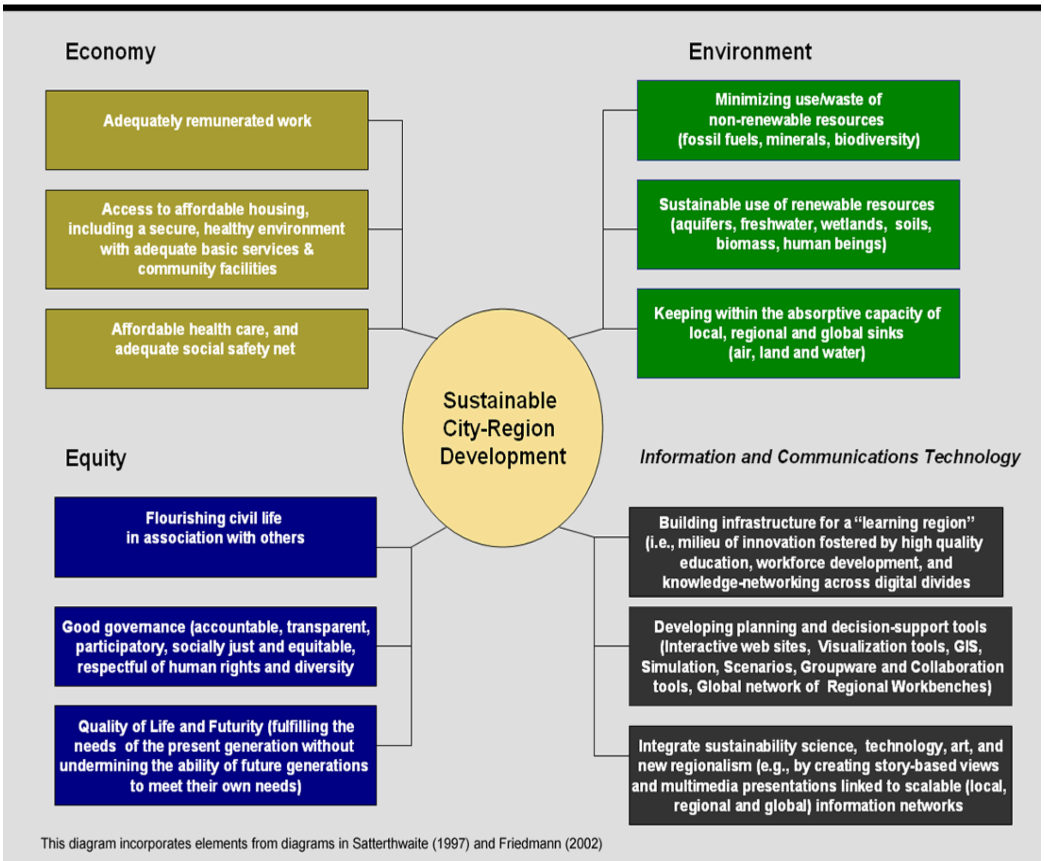


Figure 13. The elements of design sustainable urban-rural integration (Urban world system)

The following present planning and infrastructure issues, including sustainable technologies and management, for sustainable urban-rural integration.

(1)Urban and rural area planning and regulation

(2)Management of service networks

(3)Water, energy, communications, waste

(4)Transport systems

(5)Natural environment preservation

(6)Planning policies, regulations, codes, and standards

(7)Synergies and interactions between different sectors [3]

3. The holistic development of Dongtan

Figure 14. 21st-century sustainable Dongtan

3.1. Introduction of Dongtan

Dongtan is a new sustainable urban-rural integration area being planned in the Shanghai region of northern China. It aims to accommodate 80,000 people and serve as an example of sustainable development, addressing the challenges of the 21st century, including climate change and various environmental issues [4].

Dongtan is situated in an extremely strategic position very close to Shanghai. It is located on Chongming Island, which is the third-largest island in China and a sensitive wetland area at the mouth of the Yangtze River, just north of Shanghai.

Shanghai Industrial Investment Corp (SIIC), the largest international investment group company owned by the Shanghai municipal government, is the developer of Dongtan. SIIC partnered with Arup, a global design, engineering, and business consultancy, to plan and deliver the city and to undertake the integrated master planning for the Dongtan sustainable city. Founded by engineer Ove Arup in the 1940s, London-based Arup has 86 offices in more than 30 countries and a staff of nearly 9,000, including 1,500 in China [5].

Arup provides a full range of services for the project, including urban-rural integration design, planning, cultural considerations, sustainable energy management, waste management, implementation of renewable energy processes, economic and business planning, sustainable building design, architecture, infrastructure development, and even the planning of communities' social structures [6].

Eco-friendly Dongtan is arguably one of the most significant sustainable development projects being implemented anywhere on earth. Designed to be a diverse, mixed-use urban-rural integration environment, it will consist of compact villages set in parkland and intersected by canals and lakes. The project is intended to be carbon-neutral and zero-waste, while also providing employment, schools, and healthcare facilities within each urban district [7]. Dongtan will incorporate many traditional Chinese design elements and will be built in a "Chinese" style.

3.2. The strategy for sustainable Dongtan

The strategy for Dongtan is developed in several stages, with future development expected to accommodate up to around 500,000 people by around 2050, covering an area of around 30 km^2.

Dongtan is planned to develop into three pedestrian villages, each capable of accommodating about 30,000 people for living and working. These villages will include part of the marina and nearly a square kilometer of open space and parkland [8]. Dongtan aims to demonstrate that environmental sustainability and access to nature are integral parts of new development in China (see **Figure 15** and **Figure 16**).

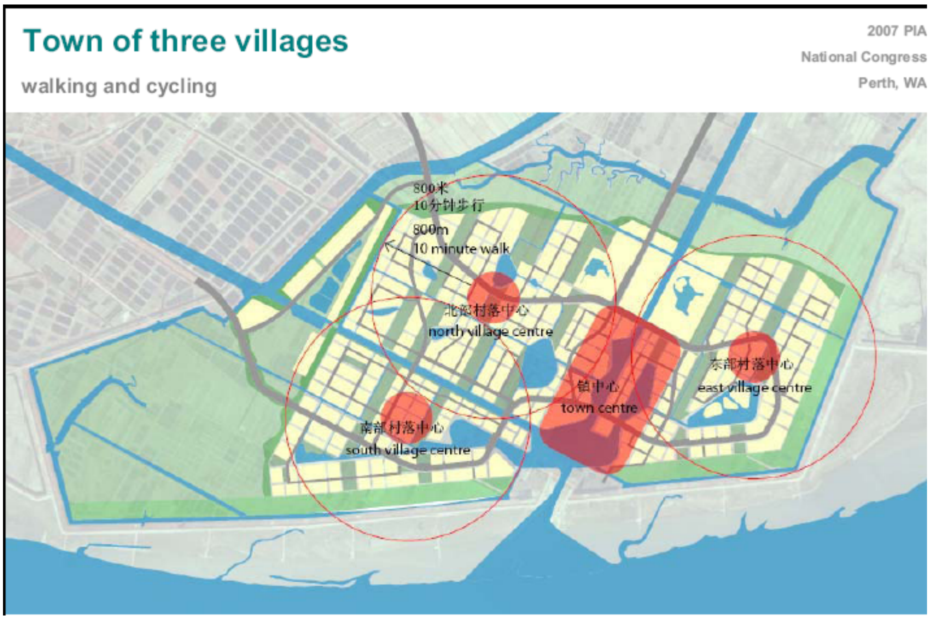


Figure 15. Town of three villages–walking and cycling

Figure 16. Town of three villages–clusters and centres

The overarching vision for Dongtan is to create a world-class sustainable urban-rural integration that is responsive to the needs of economic growth, accommodates demographic trends, and places environmental and social sustainability at the core of its development objectives. To achieve this vision, the following key objectives have been identified.

(1)To preserve the wetland habitat

(2)To create an integrated, vibrant, and evolving community

(3)To improve quality of life and create desirable lifestyles

(4) To create an accessible city

(5) Managing the use of resources in an integrated manner

(6) Working towards carbon neutrality

(7) Utilizing governance to achieve long-term economic, social, and environmental sustainability [4]

3.3. Who will live in Dongtan?

The social sustainability plan includes integrating the current population, consisting of a small fishing community and agricultural workers, into the city design rather than displacing them. The strategy for attracting and determining who will make up the additional population and how they will move into Dongtan is still being developed. However, to ensure social sustainability, the population will need to come from a wide range of backgrounds and demographics.

3.4. What will Dongtan be like?

3.4.1. Sustainability

Figure 17. Sustainable Dongtan

The aim is for Dongtan to be self-supporting, generating all its energy needs, including transport, from renewable sources, and having zero emissions from the tailpipes of vehicles. Farmland around the city will grow food for the city, and there will be nutrient and soil conditioning recycling between city waste and the surrounding land. Additionally, efforts will be made to prevent pollutants from reaching the adjacent wetland areas.

3.4.2. Energy

The city region will primarily source its energy from wind turbines, biofuels, and recycled organic material. An Energy Center will serve as the energy supply hub for the entire city of Dongtan. Furthermore, it will function as a tourist attraction, leisure park, science exhibition, and education center.

3.4.3. Climate change

The potential to facilitate climate change mitigation should involve controlling and managing greenhouse gas emissions. Moreover, maximizing Dongtan's adaptive capacity will enable effective management of future climate changes.

3.4.4. Recycling

Most of the city's waste will be recycled, and organic waste will be composted or used as biomass for energy production. There will be no landfilling of waste, and human sewage will be processed for irrigation and composting purposes.

3.4.5. Buildings

Figure 18. The bird eye view of Dongtan residential buildings

Labor and materials will be locally sourced to reduce transport and embodied energy costs associated with construction. A combination of traditional and innovative building technologies will decrease energy requirements for heating and cooling buildings by up to 70%. Good public transport will lower air and noise pollution, enabling buildings to be naturally ventilated and reducing energy demand. Green roofs on buildings will improve insulation and water filtration, and offer potential storage for irrigation or waste disposal. A compact city made of villages will lower infrastructure costs and enhance amenity and energy efficiency of public transport systems.

3.4.6. Transport

Dongtan will feature urban-rural integration linked by a combination of cycle paths, pedestrian routes, and various modes of public transport, including buses and water taxis. Canals, lakes, and marinas will permeate the city, offering a range of recreational and transportation opportunities. Public transport will incorporate innovative technologies, potentially including solar-powered water taxis or hydrogen fuel-cell buses. Visitors will be encouraged to park their cars outside the city and utilize public transport while within the city limits.

Figure 19. The master plan for sustainable Dongtan

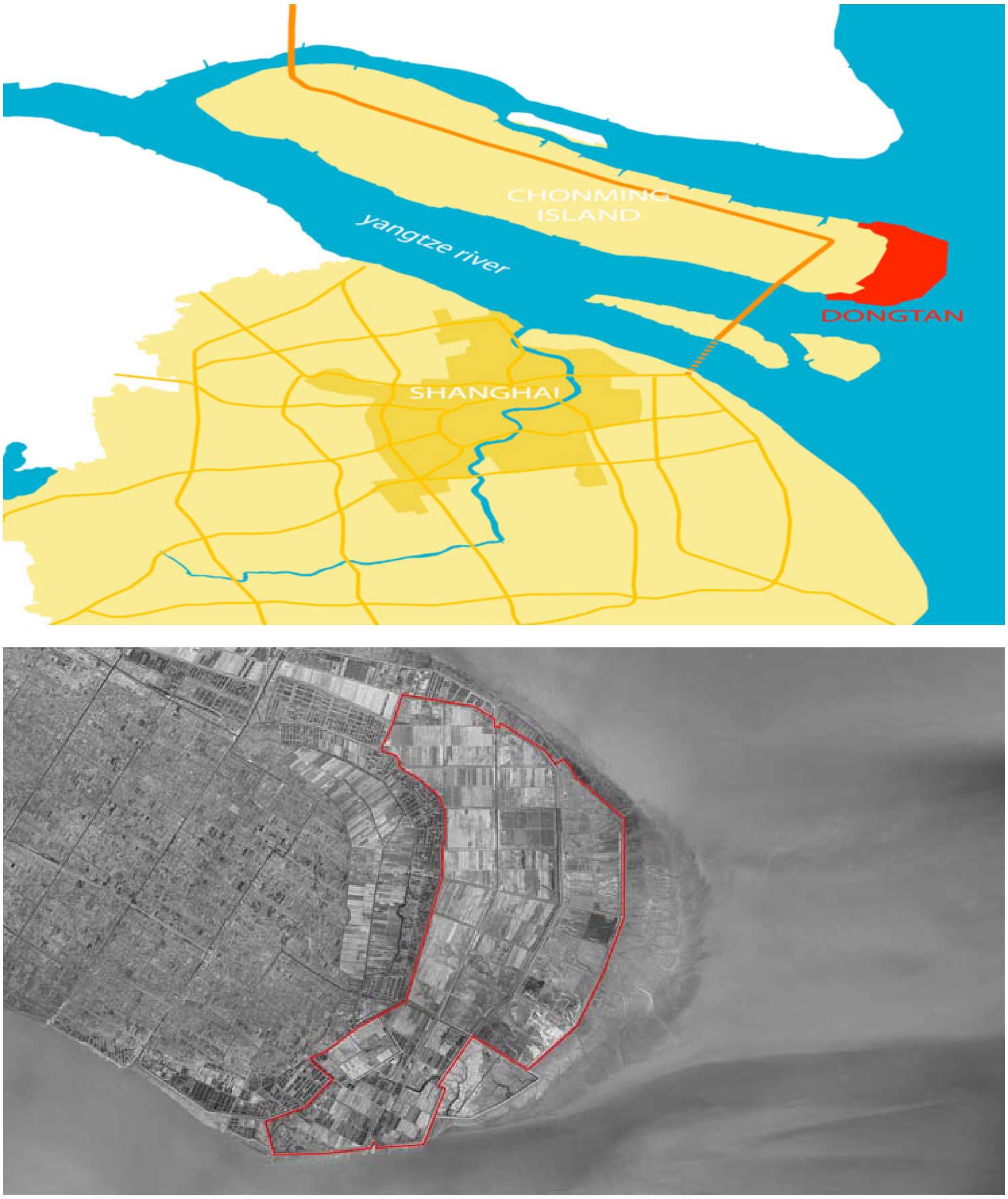


Figure 20. The geographical location of Dongtan

3.5. Science and technology

3.5.1. General design principles

3.5.1.1. Design proposal

Dongtan is designed as a modern, culturally rich, distinctly Chinese, and environmentally sustainable community. The design aims to provide a rich sensory experience—satisfying sight, sound, taste, smell, and touch—while aligning with an integrated sustainable development framework that addresses economic, environmental, and social objectives. This framework meets ambitious national, regional, and SIIC corporate goals, representing a new paradigm in urban-rural design in China, focusing on addressing environmental pollution, reducing emissions, and finding alternatives to fossil fuel depletion.

3.5.1.2. Design principles

(1) Minimising energy consumption in buildings and transport creating maximum use of renewable energy with the aim of energy self-sufficiency
(2) Closed-loop recycling where all waste is reused or recycled
(3) Maximum use of local organic fresh food
(4) Water self-sufficiency
(5) Design for zero particulate emissions from transport vehicles
(6) Design for accessibility, with homes near jobs and public services, connected dedicated safe walking and cycling routes and efficient public transport
(7) Green spaces and water features designed to increase bio-diversity and create a traditional Chinese sense of place throughout Dongtan
(8) World-class leisure, eco-tourism, health, and knowledge enterprise developments with a focus on emerging technologies
(9) Long-term robustness against the impacts of climate change

3.5.1.3. Design components

Dongtan aims to be the world's first purpose-built eco-friendly community. It is designed not only to be environmentally sustainable, but also socially, economically, and culturally sustainable. Its goal is to be as close to carbon neutral as possible, with city vehicles that produce no carbon or particulate emissions and highly efficient water and energy systems. Dongtan will generate all of its energy needs from renewable sources including biofuels, wind farms, and photovoltaic panels. A majority of Dongtan's waste will be reused as biofuel for additional energy production and organic waste will be composted. Even human sewage will be processed for energy and composting, greatly reducing or eliminating landfill waste sites.

3.5.1.4. Design

Dongtan is being designed as three village neighborhoods concentrated at the southern tip of the site. The infrastructure, including roads, public transport, schools, hospitals, commercial areas, and green spaces, will encourage inhabitants to travel by bicycle or public transport rather than cars. These villages will converge to create a city center where commercial activities will be concentrated.

3.5.1.5. Transportation

The city will be linked by a network of pedestrian walkways. Car-Pool, an intranet service, will connect people interested in carpooling and provide travel time forecasts. Only zero-carbon vehicles will be permitted within the city. Pollution-free buses, trams, or water taxis, powered by fuel cells or other zero-carbon technologies, will run between neighborhoods. Traditional motorbikes will be prohibited, with electric scooters or bicycles replacing them.

3.5.1.6. Buildings

Buildings will be dense but limited to a maximum of eight stories. Turf and vegetation will cover roofs, creating green roofs, providing natural insulation, reducing runoff, and recycling wastewater. Photovoltaic panels and small-scale windmills integrated into building designs will provide up to 20% of the power.

3.5.1.7. Waste and energy

Up to 80% of solid waste will be recycled. Organic waste will be reused for compost and energy generation, fulfilling part of the town's electricity requirements. Rice husks, abundant in Chongming's rural area, will be burned in Combined Heat and Power (CHP) plants to generate heat, cooling, and electricity. Wind turbines positioned on the outskirts of the city will harness sea breezes to produce electricity. An energy center will manage generation via wind turbines, biofuels, and recycled organic material, also serving as an information resource center for inhabitants and visitors.

3.5.1.8. Flood protection

Existing flood walls surround the site, with provisions in the design to increase the defenses' height in response to sea-level rise. Protective cells within the city's basements will serve as additional flood protection. The Shanghai Municipal Government is constructing a bridge, tunnel, and high-quality road to connect Chongming Island and the Dongtan site to the Shanghai mainland .

3.5.1.9. Energy efficiency

Dongtan expects to use 64% less energy than a comparable city of its size built in a business-as-usual manner. Dongtan will achieve carbon neutrality, with its main grid designed for walking and cycling rather than cars. The city will be powered by solar and wind power, biofuels, and recycled organic material. Green roofs will be implemented for energy efficiency and insulation benefits, while rainwater capture systems will maintain landscaping. All vehicles will operate on clean fuels, and approximately one-fourth of the city will be designated as open green space. With fewer gas and diesel vehicles congesting the streets, residents should be able to open their windows and enjoy clean air. Additionally, about 20% of the city will be reserved for affordable housing, although some farmers express concerns that it may still be out of their price range.

3.6. Dongtan sustainable development

3.6.1. The framework of development of Dongtan

Table 1 outlines the comprehensive framework for Dongtan's development, which integrates environmental, social, natural resource, and economic objectives. This framework highlights the multi-dimensional approach required to build a sustainable urban-rural integration.

Table 1. Framework for the development of Dongtan

Environment	Social
(1) Physically and legally protect the internationally significant Dongtan wetlands from any man-made intervention such as physical encroachment, poaching of wildlife, and pollution of land, water, and air. Impose the strongest possible penalties on organizations and individuals in breach of these measures. (2) Protect and enhance the biodiversity and quality of the wilder Dongtan and its urban areas including the ecological communities and habitat, canals, and waterways. (3) Avoid any physical degradation of the island through Dongtan's activities and monitor the impact of others on the rate of deposition and erosion of the eastern wetlands. (4) Enable sustainable lifestyles that minimize negative environmental impacts on resource use, waste, and pollution through the provision of well-connected, public transport links, cycling and walking routes, and the availability of healthy food produced sustainably by local farmers and fishermen. (5) Create cleaner, safer, and greener neighborhoods with ecologically sound, open spaces and landscapes that encourage social interaction and healthy lifestyles. Build with people as the priority, not cars, and encourage sustainable alternatives for the transport of freight, goods, and food. Design for the likely effects of climate change for now and the future, incorporating sustainable drainage and flood management techniques.	(1) Create inclusive, cohesive and tolerant communities that recognize traditional and modern Chinese and other cultural values. (2) Ensure all citizens can engage with and are represented by governance systems that are accountable and that work towards the continued realization of Dongtan's full potential as an eco-friendly city. (3) Develop an urban-rural integration that enables healthy and safe lifestyles through the provision of key services and facilities accessible to all and which promote health, provide suitable healthcare when required, avoid car dependence, and reduce opportunities for crime. (4) Provide jobs and cultural, leisure, community, sporting, and educational facilities for all, regardless of age or ethnicity, and make everyone aware of these opportunities through world-class information and communication technology. (5) Create an internationally, regionally, and locally accessible city with user-friendly facilities and a sustainable mix of development and housing opportunities blend with green spaces to create vibrant communities and a real sense of place.
Natural resources	**Economic**
(1) Design for energy efficiency by utilizing renewable energy at both macro and micro scales and across all lifestyle energy uses to minimize Dongtan's contribution to climate change. Produce local biomass for energy production, and maintain flexibility for future changes in energy supply and consumption. Ensure the security of energy supply at an affordable cost while encouraging efficient use. (2) Design for the reduction, reuse, and recycling of natural and man-made materials and develop policies that encourage resource management, sustainable production and consumption, and the extraction of maximum benefit from residual wastes at Dongtan, through energy production and use in agriculture. (3) Design for water efficiency in all domestic, commercial, industrial, leisure, and agricultural applications and develop infrastructure and policies that allow for the application of potable water to only those applications that require it. Identify and protect reliable sources of fresh water for now and for the future and ensure the security of water supply at a cost that is affordable whilst encouraging efficiency of use.	(1) Aim for consistent economic progress, which recognize China's old and new economies and allows for the sustainability objectives of Dongtan to be met. (2) Develop an equitable balance and mix of uses to support sustainable investment and prosperity. (3) Provide intensives for businesses that meet the sustainability objectives of Dongtan and, conversely, ensure that environmental and special costs are met by organizations that are responsible for them. (4) Provide jobs diverse enough for all and maintain a culture of innovation and business creation, together with relevant life-long training and educational opportunities. Ensure economic benefits are realized within the local community. (5) Design and maintain suitable and flexible infrastructure, homes, buildings, transport links, and information and communications technology to sustain the economic objectives of Dongtan. Ensure the city is suitably protected from flooding and extreme events.

3.6.2. Dongtan sustainable urban development

In general, the sustainable development prospect for Dongtan will involve low-energy building design, effective management practices, promotion of renewable energy technologies, innovative integration of energy supply to buildings, increased awareness among individuals, and addressing transportation issues. Dongtan's sustainable development encompasses all elements of the sustainable prospect, including land use, buildings, transport, energy, land conservation, employment/skills, viability, form and space, health, inclusion, and air quality (see **Figure 21**).

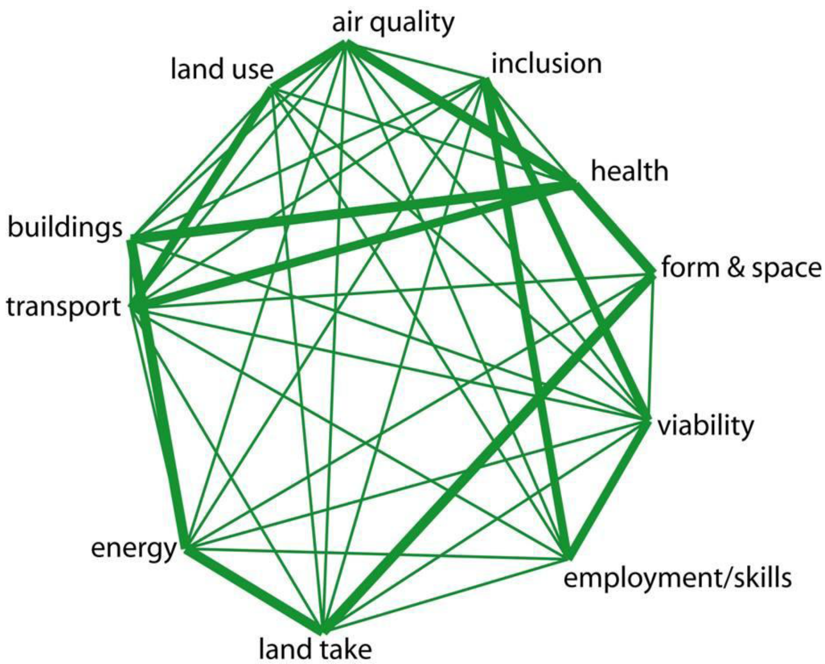
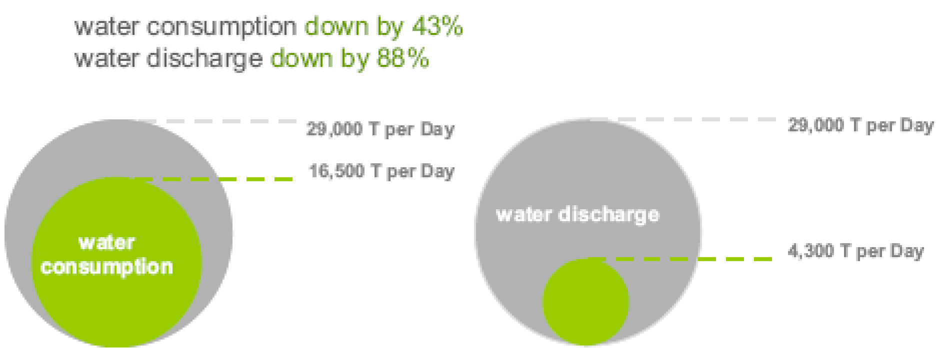


Figure 21. Elements of the Dongtan sustainable development

3.6.3 Environment

3.6.3.1 Water

Water in Dongtan is abundant, whether in canals or lakes, contributing to the city's landscape. To maintain this landscape, water in Dongtan is managed to provide a separate limited potable water supply. The water will be collected and recycled when discharged into the canals and lakes within the city boundaries. Greywater will be recycled and stored on-site. This recycled water will be used to grow green vegetables, as the intensive, relatively small amounts of water will directly reach the plants themselves. The water-saving technology can not only reduce water consumption but also further reduce energy demand and running costs while effectively controlling pollution.



Green: Dongtan

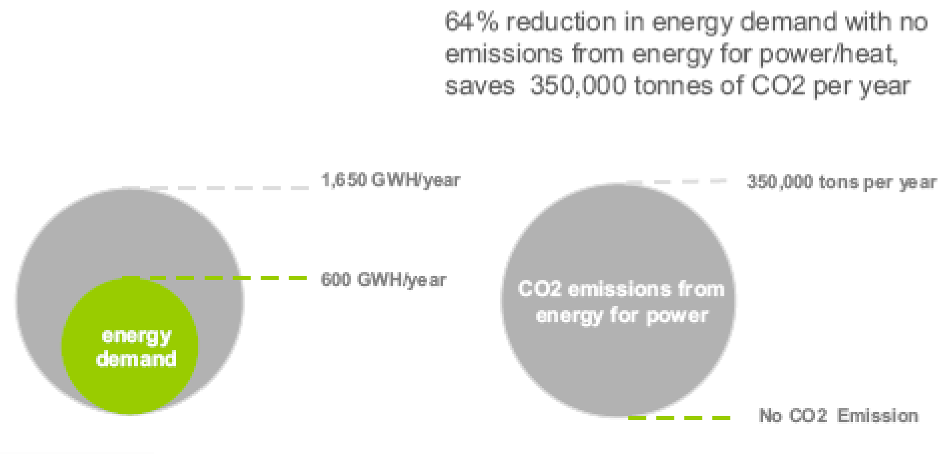
Gray: Conventional city

Figure 22. Water consumption and discharge

Conventional cities of this scale currently consume an average of 29,000 tonnes of water per day and discharge the same amount. It is estimated that Dongtan will consume an average of 16,500 tonnes per day, but only discharge 4,300 tonnes of water per day (see **Figure 22**).

3.6.3.2. Energy production, use and emission reduction

Dongtan expects to use 64% less energy than a comparable area of its size built in a business-as-usual manner (see **Figure 23**).



Green: Dongtan

Gray: Conventional city

Figure 23 Energy production, use and emission reduction

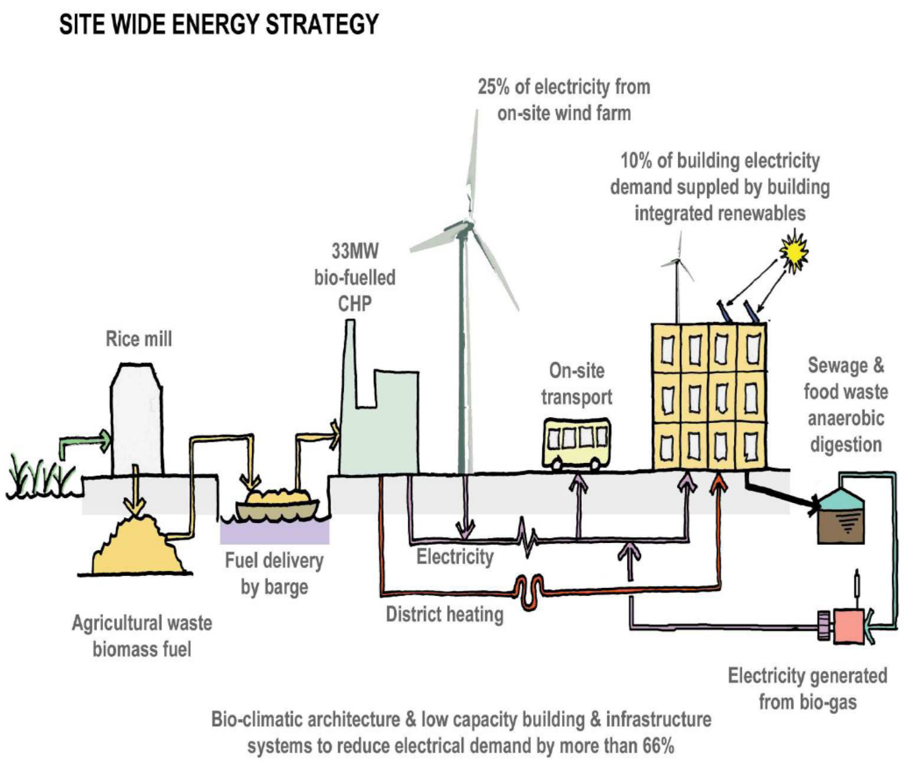


Figure24. Dongtan energy center (Mashford KJ)

3.6.3.3 Land use

Local food, organically farmed on the retained agricultural land, will be available all over the city. Traditionally, cities swallow farmland and grow at the expense of agriculture. In Dongtan, food will be grown in fields around the city and at high density using new technology in the city's food center. Though unlikely to be totally self-sufficient for food, Dongtan will produce as much food when it is built as the land did before. The agricultural industries already existing on Chongming will remain and be integrated into the way the city is run as a whole, ensuring no loss of productive land. By providing nine hectares of plant factories per 1,000 hectares of productive land utilized, the goal is to ensure Dongtan produces as much of its own food as possible.

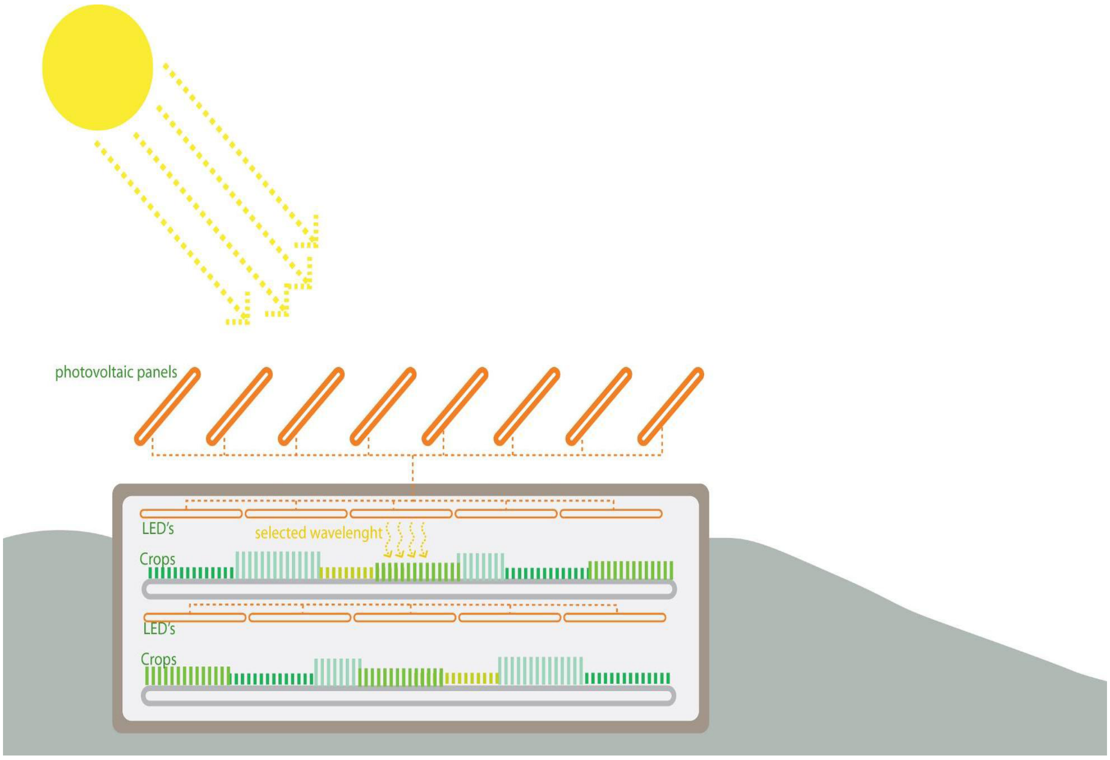


Figure25. Sustainable factory with no loss of production

3.6.3.4. Agriculture

Roughly 40% of Chongming Island will be urbanized, while 60% will remain agricultural. Sophisticated organic farming techniques linked to the waste and sewage recycling system are designed to create a sustainable cycle of local food production. Much food will be produced in innovative multi-story greenhouses lit by low-energy Light-Emitting Diode (LED) lights. The integrated approach to Dongtan's development should also mean that Chongming's existing local farming and fishing communities will have significant new business opportunities, enhancing the island's long-term environmental sustainability. Food will be processed on the island to add local value, and restaurants will also be a major feature of the local economy .

3.6.3.5. Ecology and biodiversity

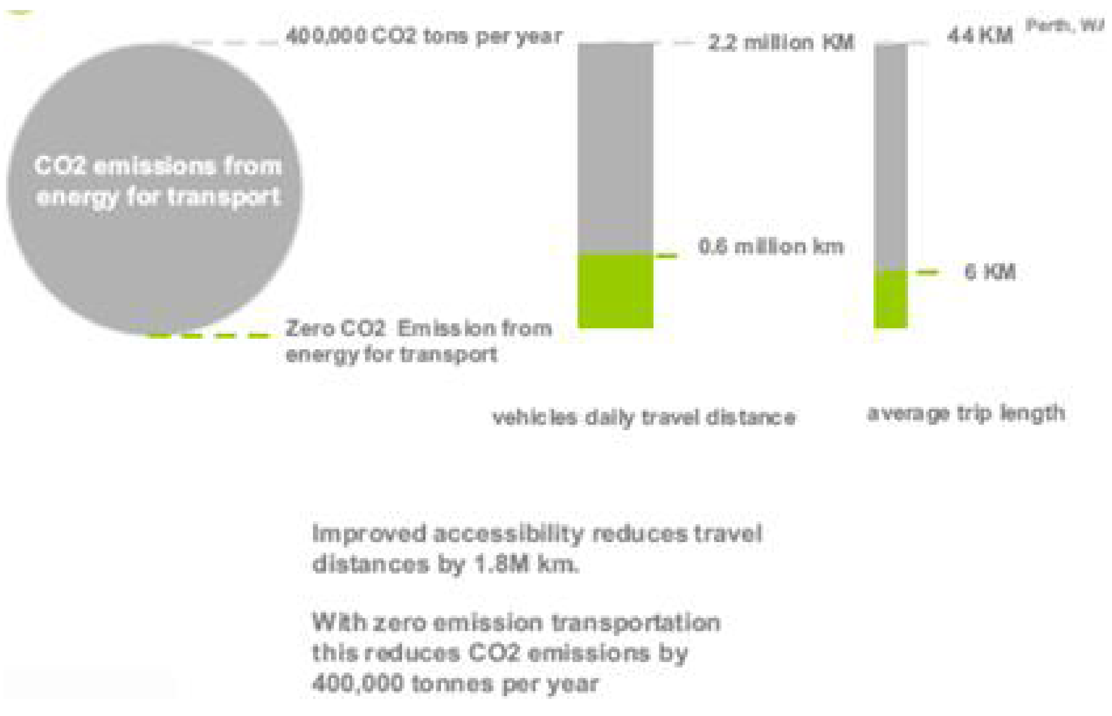
The highest priority in the Dongtan development was to protect the island's precious wetland habitat and improve the prospects of the wildlife living there, thus the natural reserve will be expanded. Chongming serves as a crucial stopover point for wildfowl on migration routes across China. The wildlife reserve at Chongming's extreme eastern tip will remain untouched and will be buffered from Dongtan by a band of eco-farming and controlled wetlands. Buildings will feature green roofs, a small difference that will positively impact biodiversity and local climate conditions. The continuous network of green spaces will create corridors for wildlife movement throughout Dongtan.

3.6.3.6. The ecological management of wetlands

The delicate nature of the Dongtan wetlands and the adjacent Ramsar site (www.ramsar.org) for migrating birds and wildlife has been one of the driving factors in Dongtan's design. The plan includes enhancing the existing wetlands by returning agricultural land to a wetland state and creating a "buffer zone" between the city and the mudflats. At its narrowest point, this buffer zone will be 3.5 km wide, with a 2-mile buffer zone of eco-farms between city development and the wetlands. Only around 40% of the land area of the Dongtan site will be dedicated to urban areas, aiming to prevent pollutants (light, sound, emissions, and water discharges) from reaching the adjacent wetland areas.

3.6.3.7. Transport

Residents in Dongtan have frequent public transport, buses, or water taxis never more than 500 m away forming a convenient accessible integrated service. Fewer roads are needed per person, reducing the up-front capital cost of development, and road layouts are arranged to serve local houses and not provide through routes, improving safety for children and cyclists. People can walk or cycle on a network of dedicated routes through the abundant green spaces to get to work, go shopping, or go to school. Dongtan will serve as the gateway to the entire canal network of Chongming. Canals are a traditional feature of Shanghai developments, and a bustling web, carrying freight, passengers, and tourists, will serve Dongtan.



Green: Dongtan Gray: Conventional city

Figure 26. Accessibility and transport

3.6.3.8. Buildings

The buildings target low-energy designs, incorporating the following features.

(1) Modest window areas
(2) Building orientations optimized for the type of building, such as more glazing to the north to reduce cooling requirements
(3) Shading overhangs to minimize direct solar gain in the summer
(4) Passive cooling techniques using night ventilation provision coupled with exposed thermal mass to minimize cooling needs
(5) An airtight building envelope to reduce summer hot air infiltration and winter heat loss through draughts
(6) Entire structure contained within a thermal insulation “overcoat” building envelope to enhance thermal insulation and avoid envelope thermal bridging
(7) Internal heat gains minimized to reduce direct electricity use and the need for air conditioning
(8) Low-energy-rated domestic and commercial appliances, with labeling systems to assist purchasers and installers in selecting products with sufficiently low energy demand
(9) All electronics are designed with low standby power requirements [4]

3.6.3.9. Waste management

All waste in Dongtan will be reused or recycled, with minimal landfill. In addition to improving the current water supply, rainwater will be collected, recycled, and managed. Conventional cities of this scale currently consume an average of 500 tonnes of waste per year. It is estimated that Dongtan will consume an average of 30,000 tonnes per year (see **Figure 27** and **Figure 28**).

Green: Dongtan Gray: Conventional city

Figure 27. Waste management (1)

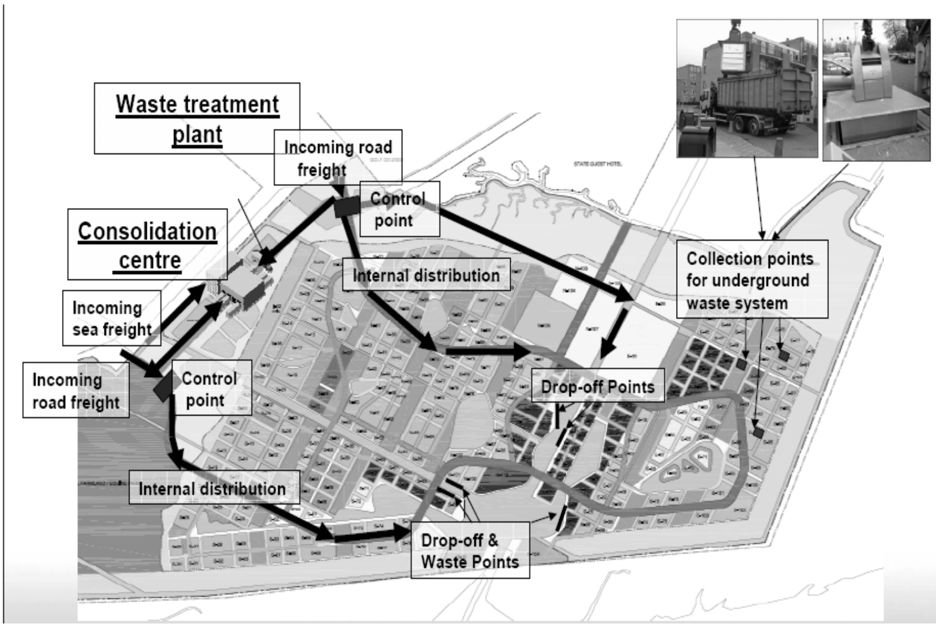


Figure 28. Waste management (2) (Briggs D)

3.6.3.10. Agriculture/city linkage

Local food, organically farmed on the retained agricultural land, will be available throughout Dongtan.

3.6.4. Social benefit

3.6.4.1. Mobility and access

Dongtan aims to attract companies focused on new technologies, food research and production, and healthcare. The developers plan to generate 50,000 jobs around Dongtan in tourism and research, focusing on a variety of "innovation-oriented industries."

3.6.4.2. Education

Schools are set up and available for people of any age in Dongtan. The workforce enjoys quality education, enabling them to become well-educated and creative workers.

3.6.4.3. Inclusion

Dongtan will provide plenty of open space for its residents, with 30 square meters per person. It will contain enough people to generate the critical mass needed for facilities such as hospitals, schools, jobs, and community groups. Keeping energy consumption for transportation to a minimum also requires the city to be compact and high density. In the city center, the intention is to have around 160 people per hectare, about four times lower than nearby Shanghai's central districts.

Contact with green spaces will be an everyday feature of life in Dongtan, with nowhere being more than a few minutes from a park. The condensed pedestrian centers will have easy access to farmland and parkland that will open out. A 142-hectare ecology park will be built to high standards in Dongtan, with a green area per capita of 27 m^2, surpassing London's 20.5 m^2 and Los Angeles's 6.6 m^2. People will enjoy a high quality of life largely dependent on the outstanding natural environment.

3.6.4.4. Health

High-quality health services can improve the urban ecological environment and protect citizens' health. Building hospitals that adapt to ensure social sustainability and the health of people is essential.

3.6.5. Economic benefit

It is expected that Dongtan will foster a vibrant and diverse economy, generating a rich variety of employment opportunities. It aims to attract people from a broad socio-economic spectrum who will contribute to a wide range of businesses. Dongtan will contribute to the region's sustainable prosperity by integrating economic development and environmental protection.

4. Conclusion

4.1. Challenges of sustainable development of urban-rural integration

4.1.1. Climate change and other environmental issues

Climate change is increasingly recognized as a significant threat, with predominant negative effects on the environment, quality of life, social cohesion, and economy. Sea-level rise, land desertification, climatic disruptions, and crop failures are among the consequences. As cities rapidly grow in number and size, and populations migrate, there is potential for unrest in the world's social and economic systems.

4.1.2. Global economic trends and urbanization

China's cities face common problems during urban development, exacerbated by the country's status as one of the most urbanized in the world, with a large population concentrated in cities and a high number of megacities. Additionally, China ranks among the highest consumers of energy and water resources globally and generates significant amounts of commercial and industrial waste.

As cities and their inhabitants increasingly recognize the significant impact of urban development, there is a growing urgency for action and solutions to address the unsustainable economic, social, and environmental problems created by human activities.

4.2. Sustainable development of urban-rural integration

The concept of sustainable urban-rural integration encompasses the ecological-economic and environmental-psychological aspects of urban-rural design and management. The overarching objective is to promote sustainable development of cities, addressing economic, social, ecological, and spatial dimensions.

4.3. Sustainable urban-rural integration design and development

The sustainable urban-rural integration plan and design should extend beyond the consideration of environmental, economic, and social factors. It should encompass aspects such as growth, green energy generation, transportation systems, community participation, land development, and ecological protection. This includes integrating sustainable technologies and management practices to ensure the holistic and long-term sustainability of urban-rural areas.

The elements of sustainable urban-rural integration design and development should include urban-rural planning and regulation, management of services networks (water, energy, communications, waste), transportation systems, natural environment preservation, planning policy development, regulations, codes, and standards, as well as fostering synergies and interactions between different sectors. These components are crucial for ensuring the comprehensive and integrated sustainability of urban-rural areas.

4.4. The case study of Dongtan

The overarching vision for Dongtan is to establish a world-class sustainable urban-rural integration that meets the demands of global economic growth, demographic shifts, and urbanization trends, while simultaneously achieving environmental, economic, and social sustainability objectives.

4.4.1. Science and technology

4.4.1.1. Design principles and technologies

Dongtan is designed to embody environmental, social, economic, and cultural sustainability principles in line with the tenets of sustainable development. It encompasses various elements such as urban-rural design, transportation, buildings, waste and energy management, energy efficiency measures, flood protection, and more.

4.4.1.2. Dongtan sustainable development

The term "sustainable urban-rural integration" denotes its incorporation as a component of a comprehensive initiative aimed at reducing a town's environmental footprint. This objective entails the utilization of various eco-technologies in construction, energy production, water management, waste management, and other areas. The Dongtan sustainable project is advanced through the adoption of technologies and efficient management practices across environmental, social, and economic dimensions.

Disclosure statement

The author declares no conflict of interest.

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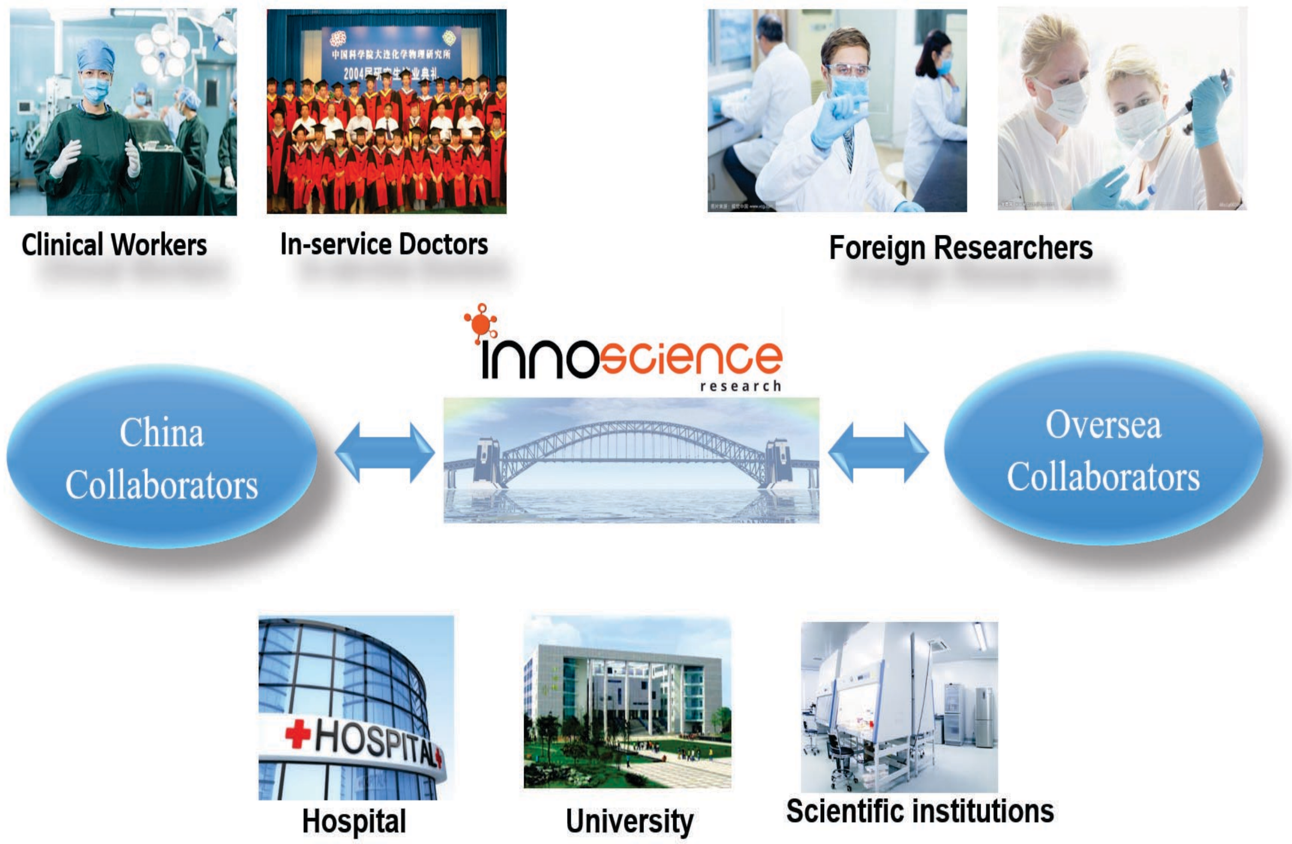

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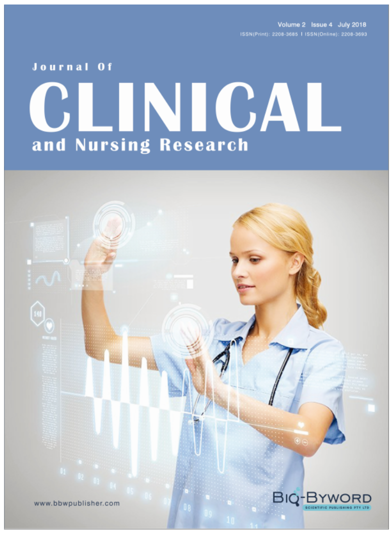

Topics covered by not limited to:

- Development of clinical and nursing research, evaluation, evidence-based practice and scientific enquiry
- Patients and family experiences of health care
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