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A Semantic-Sensitive Approach to Indoor and Outdoor 3D Data Organization

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Abstract: Building model data organization is often programmed to solve a specific problem, resulting in the inability to organize indoor and outdoor 3D scenes in an integrated manner. In this paper, existing building spatial data models are studied, and the characteristics of building information modeling standards (IFC), city geographic modeling language (CityGML), indoor modeling language (IndoorGML), and other models are compared and analyzed. CityGML and IndoorGML models face challenges in satisfying diverse application scenarios and requirements due to limitations in their expression capabilities. It is proposed to combine the semantic information of the model objects to effectively partition and organize the indoor and outdoor spatial 3D model data and to construct the indoor and outdoor data organization mechanism of "chunk-layer-subobject-entrances-area-detail object." This method is verified by proposing a 3D data organization method for indoor and outdoor space and constructing a 3D visualization system based on it.

Keywords: Integrated data organization; Indoor and outdoor 3D data models; Semantic models; Spatial segmentation

Online publication: February 26, 2024

1. Introduction

With the increasing complexity of urban construction and management [1], buildings, as the most important elements in the city, carry most of the human activities, and the main space of human activities is shifting from outdoor to indoor. However, compared to outdoor information, indoor information in urban 3D Geographic Information Systems (3D GIS) remains significantly limited. Consequently, for a comprehensive digital city application system, it is essential to integrate various buildings with indoor scenarios. This integration not only enhances our understanding of the city but also adds vitality to the application. A development pattern of outdoor to indoor will be inevitable for digital cities in the future [2].

The study of indoor data models focuses on conceptualization, standardization, and representation of the various spaces that constitute the indoor environment and its relationships, as well as adapting and customizing the existing data models according to the needs of application services [3]. Two types of models can be extended: (1) generalized indoor models for specific classes of users and (2) models for specific purposes. Many studies have based their modeling on indoor spatial standards; these include CityGML, IndoorGML, and

the IndoorGML Core Module, which consists of basic modeling components; and the IndoorGML Navigation Module, which refers to an extension of the Core Module to the IndoorGML Navigation Module. The navigation module is based on an open data model for indoor spatial information and IndoorGML, the XML schema of the Open Geospatial Consortium (OGC) standard. Unlike the object-based CityGML, IndoorGML represents indoor spaces as constrained semantic spaces, and thus IndoorGML-based models are better suited to represent the connectivity of a variety of indoor spaces [4]. Srivastava et al. proposed an extension to the IndoorGML core module aimed at merging semantic information. Consequently, the then-existing IndoorGML structure did not support semantic information storage [5,6]. Park *et al.* proposed a data model that can be easily applied to indoor spatial information services for PWDs based on the mobility of people with disabilities (PWDs) in indoor environments, which extends the attributes of the TransitionSpace module in IndoorGML [7-9]. Anchor nodes are points in IndoorGML that define a seamless connection between indoors and outdoors, but the design of this module is not detailed; at least one common opening unit (anchor node) is required to go from outdoor space to indoor space, and the anchor node can be non-existent or invalid due to a number of reasons (e.g., the disappearance of a door due to a natural disaster, or prohibiting access to a specific group of users [safe area] or allowing access to the store only according to a specific time intervals) and thus it is not possible to switch between outdoor and indoor space via anchor nodes.

In the indoor-outdoor 3D model data, a "chunk-layer-object-entrance-area-detail-object" indoor-outdoor scene data organization mechanism is constructed. Combined with the information of the model objects, the 3D model data of indoor and outdoor space is effectively divided and organized, and the integrated indoor and outdoor data organization can organically combine the data in different spaces, which makes the data flow more naturally and conveniently in the whole system. Through the indoor-outdoor integrated data organization, data can be better utilized and the value and efficiency of the data can be improved, thus better meeting the needs of different fields.

2. Indoor and outdoor 3D model data association organization method

2.1. Indoor and outdoor 3D semantic modeling

The root of the model will focus on organizing indoor and outdoor three-dimensional spatial objects. The organization will follow a spatial division structure, characterized by the "chunk-layer-subobject-entrance-area-object detail" format. The outdoor 3D model objects include buildings, transportation facilities, vegetation, and other ancillary facilities models, etc. The indoor 3D model is the basic spatial element data that constitutes the indoor scene, and it is mainly for the indoor fine architecture and equipment facilities 3D model data. The main semantic element is the name of the model object, such as road, building, door, window, wall, room, etc. Specific semantic information can be assigned to indoor and outdoor 3D models according to the naming rules shown in **Figure 1**.

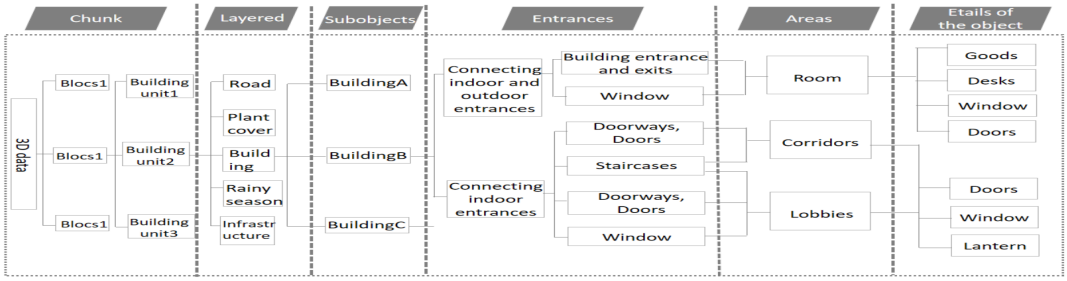


Figure 1. Semantic organization of indoor and outdoor 3D model data

Chunking according to the working or administrative area: chunking serves to seamlessly divide the modeling area into chunks horizontally. The area is divided by natural, artificial, or administrative boundaries. Each chunk of the same boundary should be kept in a moderate size to avoid excessive differences.

Layering by elements: layering serves to vertically divide the modeling objects according to different types, which can be classified according to the classification of urban 3D models, i.e., building models, traffic facilities models, pipeline models, greening models, and other models. More subdivisions can be made on this basis. Outdoor space building objects can be classified into different buildings, e.g. Building A, Building B, and Building C.

A portal is defined as a spatial object through which regional objects are interconnected. It may be model objects that exist directly in the 3D model, such as doors, windows, etc. Semantic information are assigned to such model objects and these categories of objects are added to the list of entrance categories so that they can be extracted directly as entrance objects (e.g. Door1_Room321). In contrast, entrances such as patio doors that do not have corresponding model entity objects are represented by adding transparent model objects, which ensures the correctness of the visualization while guaranteeing the completeness of the area-entrance structure in terms of model object correspondence.

Most of the indoor spaces are composed of several independent functional areas, such as rooms, corridors, etc., and each functional area is connected by doors and other entrances. Each functional area is given a unique name (e.g. Room_321), and the area object is required to be an independent spatial unit that can form a closed space. Area categories are managed by a list, with objects containing extracted name semantic information from this list being categorized accordingly.

In indoor 3D space, the objects and furniture in the room should be separated from the area models and be made independent. This separation is essential for equipment management. Additionally, since the data volume for objects within a room is typically much larger than that of the building itself, it is often necessary to construct detailed level models to mitigate data volume during the visualization process. The object models in the room are extracted as detail objects according to the application requirements, and the required semantic and attribute information are added to these objects (e.g. Desk1_Room321). The detail objects are associated with the region objects in a containment relationship.

2.2. Indoor and outdoor data association processing

The indoor and outdoor 3D data processing and organization proposed in this paper does not consider the large range of raster data such as DEM or DOM. Instead, it only contains indoor and outdoor 3D models and other 3D urban spatial models that are distributed complexly in terms of buildings. the quadtree and octree organization and indexing methods do not conform to the spatial distribution rules and visualization characteristics of indoor and outdoor scene data. Therefore, we need to establish a data indexing organization method that conforms to the characteristics of indoor and outdoor roaming and visualization (**Figure 2**).

Based on the indoor and outdoor 3D semantic model, the model of indoor and outdoor space is divided into six categories for extraction and segmentation: chunking achieves reasonable partition of the 3D scene, dividing the complex 3D scene into multiple smaller regions, making the management and processing of the scene more efficient and flexible; layering categorizes the 3D scene according to different elements, and each element is represented as an independent model Monoliths, such as roads, vegetation, buildings; sub-objects represent independent buildings in outdoor space; entrances represent connecting objects between areas such as doors between rooms and corridor passages, and windows between rooms and outdoor areas. Detail objects

denote relatively independent 3D model monoliths such as tables, chairs, and computers; regions denote spatially functional regional objects such as rooms, corridors, and halls.

According to the semantic information, on the basis of each type of object preserving its own attribute information, all types of objects are integrated according to the subordinate relationship between regions and the connection between objects, forming a chunk-layer-subobject-entrance-area-detailed object structure.

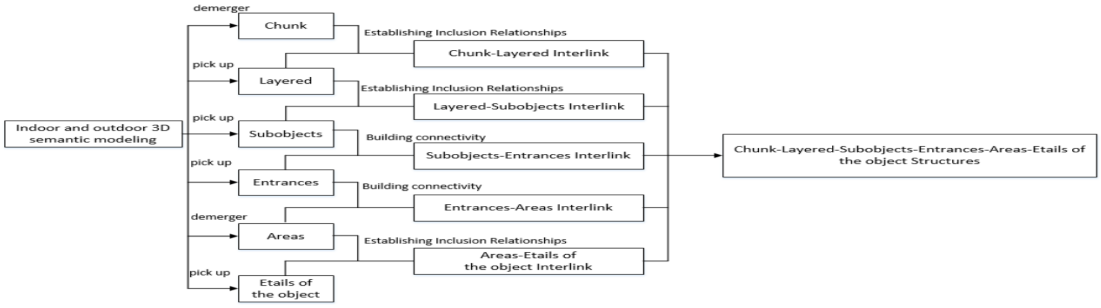


Figure 2. Indoor and outdoor data correlation

2.3. Indoor and outdoor 3D model data organization

The outdoor 3D scene data is organized using traditional quadtree organization. The process involves determining the location of the indoor building model and obtaining the quadtree leaf node containing the building's three-dimensional model. This leaf node encompasses outdoor 3D scene data such as roads, vegetation, infrastructure, and other elements. Additionally, connections between indoor and outdoor entrances are added to the outdoor area, facilitating integration between indoor and outdoor spaces. This is illustrated in **Figure 3**.

The 3D scene data are organized using a traditional quadtree. The leaf nodes of the quadtree containing the 3D model of the building containing the indoor model are determined by the location of the building containing the indoor model. These leaf nodes contain outdoor 3D scene data such as roads, vegetation, and infrastructure data. Buildings and objects connecting indoor and outdoor entrances are also added to the outdoor area to increase the completeness and realism of the scene. Large-scale outdoor scene data can be easily managed and indexed using a quadtree. By dividing the scene into nodes of a quadtree, the data in a specific area can be quickly located and retrieved, increasing the efficiency of data access.

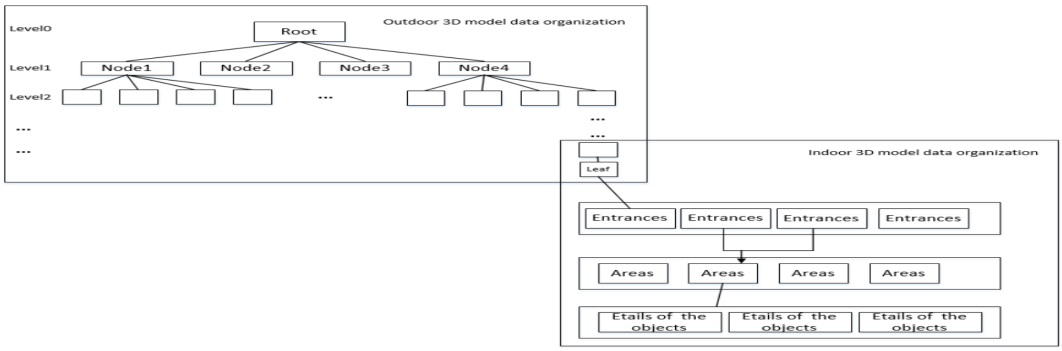


Figure 3. Indoor and outdoor 3D data organization methods

3. Experiment

In order to verify the practicality of the method proposed in this paper, conducted indoor-outdoor 3D data visualization experiments. **Figure 4** and **Figure 5** show the visualization effect and fluency experiments using

the method in this paper. When observing the roaming visualization effect, the method employed in this paper demonstrated minimal stagnation or deformation, resulting in smooth and fluent roaming. Comparing the initial data input volume, Moments 1 and 3 showed slightly lower values than the traditional method, while Moment 2 remained equal to the traditional method. However, in terms of response time, the method proposed in this paper significantly outperformed the traditional method across all three moments. This means that the proposed method can organize indoor and outdoor 3D data faster with the same amount of data transfer.



Figure 4. Visualization of renderings

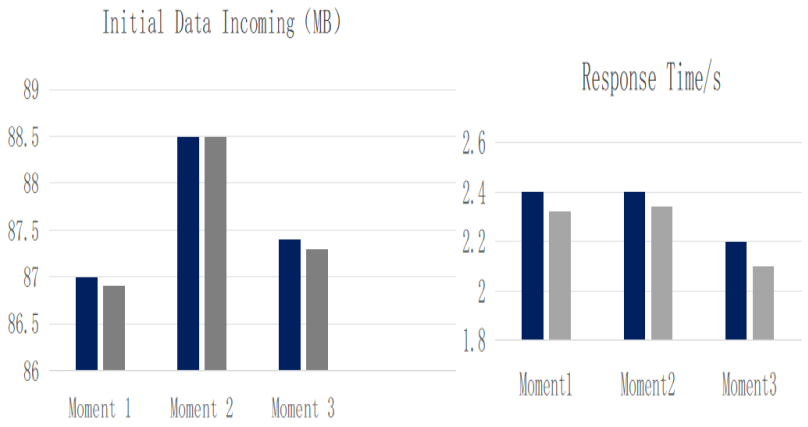


Figure 5. Fluency comparison

4. Conclusion

A semantic integrated organization method for indoor and outdoor 3D model data was proposed in this paper, which organizes the indoor and outdoor 3D model data in the form of "chunking-layering-objects-entrances-areas-detail objects." With the continuous development of digital building technology, the integrated indoor and outdoor data organization will be improved to provide more powerful support and guarantee for the construction of smart cities.

Disclosure statement

The author declares no conflict of interest.

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Research on Urban Building Parametric Modelling Method Based on CityEngine

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Abstract: With the advancement of technology and the development of cities, urban planning and management methods are also constantly improving. From paper-based assignments to modern digitization, new technologies have enabled more efficient design and management for cities. 3D modeling can used to simulate the urban environment, which can assist in urban planning and management. However, large-scale modeling cannot be achieved through existing modeling methods, and there are still some shortcomings in the maintenance of the model. Therefore, this article proposes a Computer Generated Architecture (CGA) parametric 3D modeling method based on CityEngine. Research on expanding and customizing modeling rules to create indoor and outdoor modeling rule templates for buildings and methods for generating urban 3D models have been carried out. The results have shown that the completed model can be displayed on different platforms thanks to parameterized modeling. The model can be modified easily and directly applied to the analysis and decision-making of urban planning schemes.

Keywords: CGA rules; Urban planning; Texture mapping; Parametric modeling

Online publication: February 26, 2024

1. Introduction

With the digitalization of urban information, related technologies are constantly maturing and developing, and the methods of urban planning and management are gradually shifting towards digitization and intelligence [1]. Urban Geographic Information System (UGIS) is an important part of the digitization of urban information. Its principle involves collecting, storing, managing, querying, and analyzing various spatial and non-spatial data using computer hardware, software, and network technology. UGIS will also serve as an advanced tool for modern urban management, planning, and scientific decision-making, making it a part of urban infrastructures. 3D GIS technology is developed from 2D GIS technology, which can intuitively reflect the formal situation of the relevant area through 3D data and increase the detailed representation of the model. Compared with traditional 2D GIS, 3D GIS provides a more realistic representation of the city as it is built upon more information, which facilitates the portrayal of spatial relationships [2].

With the rapid advancement of urban construction and the modernization of urban management, the

demand for multi-temporal, high-resolution, and 3D simulation that can express relevant geographic spatial data is also increasing in building construction and urban planning. An accurate 3D simulation of the terrain, landforms, and urban conditions can facilitate planning approval, construction, and other works of the government [3]. The use of 3D GIS in urban planning and design will grow in popularity in the future. 3D GIS is currently widely used in urban planning and design, including land use planning, urban building planning, and transportation planning [4].

This article adopts the parameterized modeling concept based on CityEngine and CGA modeling rules. By compiling and improving the modeling parameters and rules of indoor and outdoor buildings, a "modeling analysis compilation" is created, which can act as a guide for urban building designs.

2. Research methodology

2.1. Parametric modeling

Parametric modeling is the process of establishing and analyzing a model through parameters (variables) rather than numbers, and new models can be established and analyzed by simply changing the parameter values in the model. The advantage of doing so is that the parameter values can be modified easily, allowing for different analyses and optimizations of the model [5]. Through parameterized modeling, the key features of a problem can be abstracted into parameters, transforming the problem into a function of parameters. In this way, corresponding models and results can be obtained after changing the relevant parameters. This model can be used to analyze different problems, optimize parameter selection, and deduce the relationships between parameters [6].

2.2. Urban building parameter design

Parametric modeling is the process of abstracting the geometric features of a 3D model, mapping them to variable parameters, and controlling the values of each parameter to achieve changes in model size and shape.

The basic parameters of urban building models can reflect the basic performance and characteristics of buildings, as shown in **Figure 1**. The parameters calculated include building specifications, building types, coordinate parameters, and indoor specifications. The building specifications are mainly divided into building area (above ground and underground parts) and building height. The types of buildings are further subdivided into texture materials (brick, wood, glass, concrete, etc.), building functions (classrooms, laboratories, dormitories, etc.), and building layouts. The coordinate parameters for model positioning include X, Y, Z coordinates, and UV coordinates during model mapping. The parameters of the indoor model include indoor area, window area, and indoor layout. The design of basic parameters plays a crucial role in the subsequent changes and maintenance of the model, as shown in Figure 1.

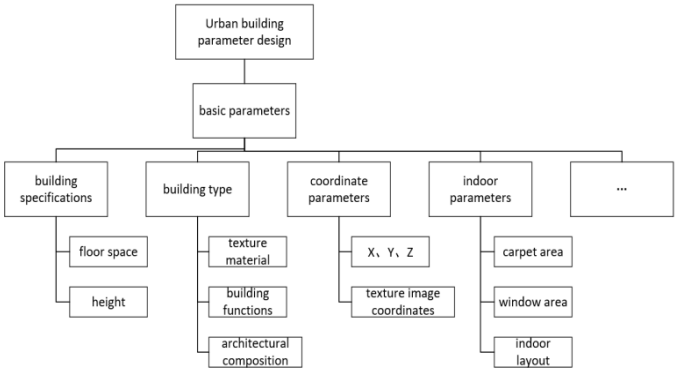


Figure 1. Basic parameters of urban buildings

2.3. Construction of urban building model based on CityEngine

2.3.1. CGA rules

CGA rules are modeling rules customized by the CityEngine platform, which define a series of rules that determine how the model is generated. All modeling in CityEngine software is created through CGA rule-driven creation. CGA rules are divided into standard rules, parameter rules, conditional rules, and random rules. When existing rules cannot meet user needs, users can create their own rules. Custom rules can be used to update already built models, reducing workload and improving modeling efficiency.

2.3.2. Building modeling

(1) To define the properties of a building for modeling regular individual buildings, it is necessary to first establish the properties of the building, select or create appropriate CGA rules, and define relevant parameters and variables, mainly including texture settings, window parameters, floor height, etc.

(2) After the property definition of the building is completed, the plot can be stretched, and the building frame can be established from the ground according to the overall height of the building, splitting the roof and facade.

(3) Applying texture to building models can be done using existing images on the platform or using self-collected texture images. Simply change the texture rules in the CGA rules. **Figure 2** shows the CGA rules used in building modeling and their corresponding renderings.

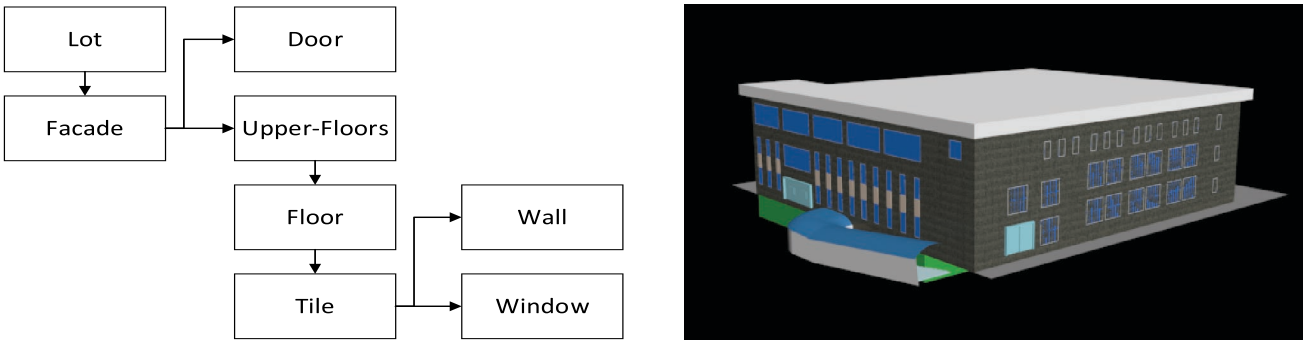


Figure 2. CGA rules and modeling effects used in the modeling of teaching buildings

2.3.3. Indoor modeling of buildings

When using CityEngine for internal 3D modeling of buildings, the first step is to assign a base map to each floor of the building based on the internal plan of each floor. These base maps include the internal and external contour lines of the building. The internal contour lines are the basis for generating the internal structure of the building model, and the external contour lines are used to generate the outer shell that surrounds the internal structure of the building. These base maps were added with a type attribute when edited in ArcMap, and the value of this type attribute can be read during rule writing. Based on this type attribute value, the internal type of the building can be determined, and different rules can be written for different types to create 3D models of the interior of each floor of the building. At the same time, in the data preparation stage, the number of floors corresponding to each building was recorded. After importing the building base map from ArcMap into CityEngine, different floors are identified through a loop, and the contour and wall of each floor of the building are generated using the CGA rule's stretch and translation functions based on the internal and external characteristics of the floors. **Figure 3** shows the CGA rules used in indoor building modeling and their corresponding renderings.

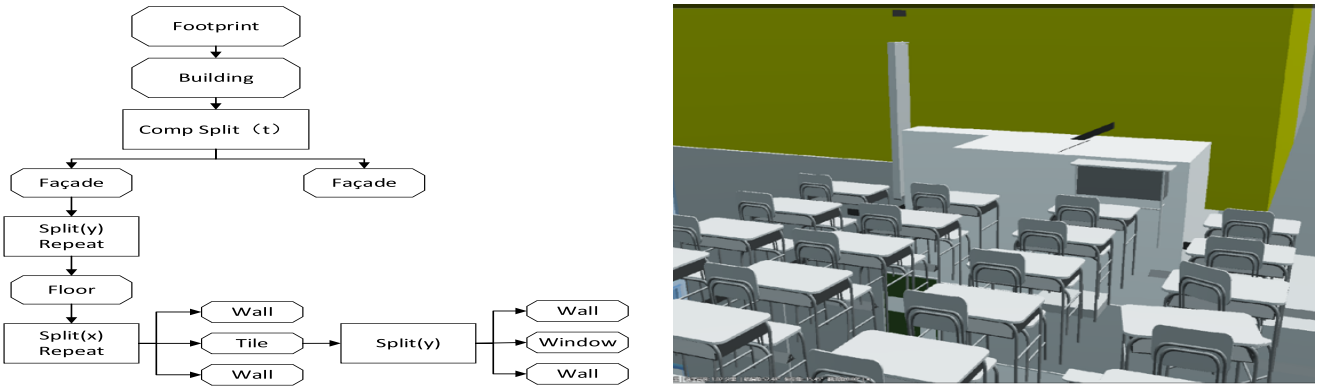


Figure 3. CGA rules and modeling effects used in the modeling of indoor buildings

3. Experiment

3.1. Preparation of experimental data

The experimental data of this article includes building vectors, building height, digital elevation models, and texture. The 3D model of the building was roughly divided into two parts, namely the three-dimensional model of the exterior facade of the building and the establishment of its internal model. The 3D model of the exterior facade usually requires the preparation of digital elevation models (DEMs) and their terrain base projection maps, while the three-dimensional internal model requires the preparation of data such as distribution maps of each room on each floor of the building. In addition, a Document Object Model (DOM) of texture and orthophoto images was created for texture mapping. Due to the large amount of data, scene areas were divided based on the distribution of urban landforms and features. Scene models were created according to the scene hierarchy (high to low) and from coarse to fine in each area.

3.2. Modeling process

Data regarding the foundation of the building was converted into the ArcGIS Shapefile or File Geo database format. As CityEngine can only set projection coordinate systems, it is necessary to perform projection conversion on the modeled data. As the foundation of parametric modeling, it is also necessary to enrich the attribute information of objects. Design parameters were assigned based on building requirements to building model components and the model was imported into the CityEngine scene. The parameter rules were written according to the modeling approach and the characteristics of campus architecture. 2D planes of each component were selected and corresponding rules were assigned. Subsequently, numerous models were generated. The next process after generating the building models was texture mapping.There are a total of six texture layers in the CityEngine system module, which have a one-to-one correspondence with UV sets (texture coordinate system sets). The process of texture mapping is shown in **Figure 4**. **Figure 5** shows the modeling effect of urban architecture.

4. Summary

The CGA parameterized modeling method was tested in this study. Compared with current 3D modeling methods, this method can reduce a lot of repetitive manual operations. By compiling, creating, managing, and updating 3D models through shape syntax, it can quickly build 3D models of buildings and roads, and also conveniently modify and maintain model data. In addition, CityEngine and ArcGIS can be linked seamlessly,

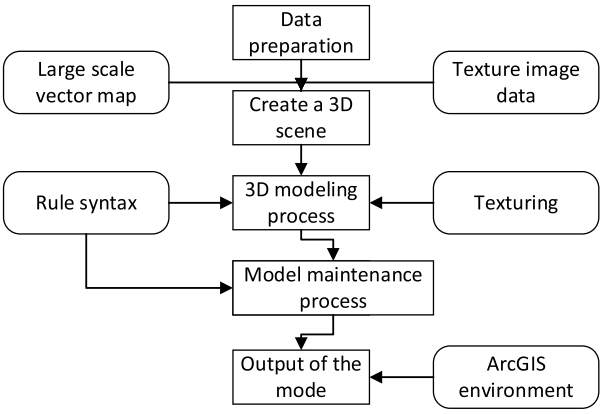


Figure 4. Urban building modeling process



Figure 5. Modeling effect of urban architecture

making the output, storage, management, and visualization of model data extremely convenient. The 3D model of urban scenes created in this experiment can be applied in digital city platforms, playing an important role in urban planning, resource allocation, and environmental maintenance.

Disclosure statement

The author declares no conflict of interest.

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Advancements and Applications of Polyurethane Curing Technology in Railway Track Bed Construction in China

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Abstract: This paper examines the application of polyurethane curing technology in the construction of railway track beds, with a specific focus on its implementation in China's rapidly developing railway infrastructure. The study begins by identifying the limitations of traditional ballasted track beds, especially under the demands of high-speed and heavy-load railways. It then methodically analyzes the advantages of polyurethane-cured track beds, highlighting their improved mechanical properties, including enhanced stability and durability. The paper further explores the benefits of transitioning to prefabricated polyurethane track beds, emphasizing significant cost reductions, better construction quality, and enhanced maintainability. Through a detailed review of experimental data and practical applications, the paper demonstrates the efficacy of polyurethane track beds in various railway settings. A critical part of the research involves optimizing the structural parameters of polyurethane track beds to achieve the best balance of mechanical and damping properties. The conclusion of the paper underscores the potential of polyurethane curing technology as a transformative approach to railway track bed construction, offering a solution to the challenges posed by traditional methods and aligning with the evolving needs of modern railways.

Keywords: Polyurethane curing; Railway track bed; Infrastructure optimization; Prefabricated construction

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1. Working principle and basic components of polyurethane-cured track beds

The curing of ballasted railway track beds involves the infusion or spraying of a curing material onto the gravel track bed once it meets the relevant design and construction standards, thus consolidating the granular track bed into a unified structure. The curing of ballasted track beds mainly involves two stages: rigid curing and elastic curing. Rigid curing, which utilizes cement mortar materials, has been progressively replaced by ballastless tracks; elastic curing primarily employs materials like asphalt, epoxy resin, and polyurethane. However, asphalt-cured track beds alter the fundamental function of ballasted beds, offering poor maintainability and a shorter service life. Due to the lack of toughness, poor impact resistance of epoxy resin, and the propensity for brittle failure, its practical application is limited. As one of today's six major synthetic materials, polyurethane, with

its exceptional physical and mechanical properties, good environmental adaptability, and durability, has found widespread application in various fields and has become the main material and direction for the development of curing ballasted track beds.

Initially, railway tracks mainly utilized traditional ballasted beds, a design that, while simple, required frequent maintenance. With the growing demands of railway transportation and the development of high-speed railways, the limitations of traditional track bed structures began to become apparent, especially under high-speed and heavy-load conditions. To enhance the stability of railway lines and reduce maintenance demands, researchers began to explore new track bed materials and technologies. Polyurethane, a polymer material known for its unique elasticity and durability, was considered for use in railway track beds. Initially tested in experiments and small-scale projects, polyurethane-cured track beds showed that this material could significantly improve the stability and lifespan of track beds. As the technology matured and more successful cases emerged, polyurethane-cured track beds began to be applied more broadly in railway networks. These track beds have been laid in experimental sections totaling 5200 meters on lines such as the Beijing-Guangzhou, Shanghai-Chengdu, Longzhang, Wari, and Daxi Passenger Dedicated Lines, covering conditions such as mixed passenger and freight transport, heavy loads, and high speeds of 250 and 350 km/h.

The polyurethane materials currently used for ballast bonding and curing mainly consist of polyisocyanates (Component A) and polymer polyols (Component B), forming a spatial network structure through covalent bonds. Component A typically comprises one or several mono-, di-, or polyisocyanate monomers, polymers, and prepolymers; Component B is made up of one or several polyether (or ester) polyols, catalysts, blowing agents, chain extenders, antioxidants, fillers, etc [1].

During the construction of a track bed, polyurethane is injected in the form of liquid into the gravel track bed. It then undergoes a chemical reaction to cure, forming an elastic solid. This process involves polymerization and crosslinking reactions, ultimately producing a continuous, elastic, and integral structure. The cured polyurethane structure exhibits excellent elasticity and compressive properties, effectively binding the gravel particles together and enhancing the overall stability and load-bearing capacity of the track bed. In the cured track bed, polyurethane serves as an effective damping layer, helping to reduce vibration and noise, a feature particularly important for railways located in urban or densely populated areas.

2. The advantages of polyurethane track beds

Firstly, a polyurethane-cured track bed is not a granular structure but a consolidated, integral one. Under the impact and vibrational load of trains, there is no relative displacement between ballast particles, thus reducing residual deformation of the track bed. Moreover, the gaps between gravel particles are filled with compressed expanded polyurethane, partially transferring forces and reducing stress at the contact points (surfaces) of the gravel particles. This delays the breakage and pulverization of ballast particles, consequently decreasing the cumulative deformation of the track bed.

Secondly, the polyurethane interspersed between the ballast particles in the cured track bed possesses elasticity, rendering the connections between these particles flexible. Hence, the internal structure of the polyurethane-cured track bed can tear along the polyurethane extrusion layer without causing damage to the ballast particles, ensuring good elasticity under train loads.

Thirdly, the cooperative working state between the polyurethane track bed and sleepers is similar to that of a gravel track bed. The relationship between the sleeper and the track bed is not completely consolidated. Utilizing the elasticity of the track bed not only prevents tamping between the bottom of the rail and the top surface of the track bed but also allows for the insertion or pouring of a layer between the bottom of the sleeper

and the top surface of the track bed to elevate the rail, similar to ballast tamping or blowing operations on conventional tracks. This provides convenient maintenance conditions, meeting the repairability requirements of the track bed.

Fourthly, various aging tests demonstrate that the polyurethane foam material used in the polyurethane-cured track bed exhibits excellent aging resistance under harsh conditions.

Fifthly, polyurethane foam material possesses exceptional weather resistance, maintaining stable comprehensive performance over long periods under various external environments. Based on data from accelerated artificial wet-heat aging tests and using the time-temperature superposition method, the service life of polyurethane foam material used in polyurethane-cured track beds is estimated to be as high as 45.2 years [2]. The physical and mechanical properties of the polyurethane foam meet the load-bearing requirements of track beds in railway structures. The results of aging and weather resistance tests indicate that the polyurethane-cured track bed can adapt to different transportation environments, offering stable and reliable performance. The polyurethane foam material ensures the objective of maintenance-free service for up to 30 years. This is particularly significant for railway sections where maintenance and construction are impractical or inconvenient.

Sixthly, polyurethane curing materials bond well with the ballast, significantly increasing the longitudinal and lateral resistance of the track bed, and maintaining good track gauge stability. All dynamic test indicators are within the limits of the evaluation standards. Compared to ballastless tracks, polyurethane track beds reduce vibrations by 2.8 to 7.4 dB in the time domain and lower noise by 0.9 to 2.6 dB [3]. The comprehensive tests on the Daxi High-Speed Railway have successfully verified the excellent performance of the polyurethane-cured track bed, playing a significant role in enhancing the technology of ballasted tracks for China's high-speed railways and enriching the variety of high-speed railway track structures.

3. The prospects of polyurethane track bed curing technology in China

The direction of modern railway development is towards high-speed passenger and heavy-load freight services. By the end of 2014, China's high-speed railway operation mileage had surpassed 16,000 km, ranking first in the world. Of this, nearly 11,000 km are equipped with track beds, mainly used on all lines of 250 km/h high-speed railways except for tunnels over 6 km, and on large bridges and major stations of 300 km/h or faster railways. China is also a world leader in heavy-load railway technology. For instance, the Daqin Railway reached an annual transportation volume of 440 million tons in 2011, the highest globally. The 1269 km long Central-South Shanxi Railway Corridor started operations at the end of 2014, and the 1817 km long Mengxi to Central China coal transport corridor began construction at the end of 2012. These lines are characterized by their length, numerous tunnels (accounting for over 25%), and large axle loads (with a design axle load of 30 tons). Due to the prevalence of ballasted tracks in heavy-load railways, increased total weight leads to significant ballast breakage and pulverization, exacerbating track bed contamination. This causes a decrease or loss of track bed elasticity, deteriorating drainage capability, leading to damage to track components, exceeding geometric dimensions, and mud pumping and fouling issues, thereby significantly increasing maintenance. Particularly in tunnels, where maintenance environments are poor, and considering that some older heavy-load railway tunnels are not suitable for large screening machines, maintaining good track bed conditions is extremely challenging and has severely impacted the efficiency and safety of heavy-load transportation.

The most effective technical approach to improve the stability of visible tracks on large-span bridges of high-speed railways, switch areas, rail expansion joint areas, and the dirt and elasticity issues of ballasted tracks in heavy-load railways, is track bed solidification.

Therefore, polyurethane track bed curing technology has great development prospects in China.

(1) Research on combining ballast bonding with expanded solidification in the cured track bed structure
Fully leveraging the drainage performance of the ballast-bonded track bed eliminates the need for specific drainage design; capitalizing on the ability of the cured track bed to enhance elasticity.

(2) Developing a fastening system that complements polyurethane-cured track beds
When ballast bonding technology is applied to the transition section of ballastless and ballasted tracks, due to the superior elasticity of ballastless track fastenings, a sudden change in stiffness is likely at the junction of ballastless and ballasted tracks. Therefore, a fastening system for the ballasted track's ballast bonding area should be developed to ensure an even distribution of stiffness in the transition section.

(3) Developing low-expansion and environment-resilient polyurethane curing materials
By reducing the expansion force of polyurethane materials, the impact on track smoothness during construction is minimized, eliminating the need for pressure maintenance measures. Versatile polyurethane materials should be developed to reduce the cleanliness requirements of ballast and obviate the need for drying measures.

(4) Developing separate and portable unit-type construction equipment for drying and pouring processes
Current polyurethane-cured track bed construction equipment requires loading on 7 flat cars, which leads to low efficiency and multiple constraints on operational lines. Separating the drying and pouring processes and developing unit-type construction equipment can achieve high-efficiency operations within limited work windows.

(5) Developing simple, feasible, and economical maintenance and repair technologies
Due to the integrality of ballast bonding and cured track beds and the lack of maintenance experience, there is a need to study corresponding maintenance and repair methods for both dynamic and static changes and emergencies.

4. Limitations of polyurethane track beds

Firstly, the curing process of polyurethane places a high demand for the cleanliness and moisture content of the ballast. As a result, on-site cast polyurethane-cured track beds impose stringent requirements on every stage of ballast handling, including loading, unloading, storage, transportation, and compaction. Additionally, specialized equipment is needed to dry the ballast before pouring, leading to a substantial increase in construction costs. This contributes to the overall higher cost of constructing polyurethane-cured track beds.

Secondly, the requirements for ballast and structural cross-sections in polyurethane curing are based on existing design standards of high-speed railway ballasted tracks. However, the foaming of the polyurethane curing agent significantly enhances the mechanical properties of the original granular track bed. Continuing to use the existing design standards for high-speed ballasted track structures will inevitably lead to a conservative structural design with excessive safety redundancy, which is a major factor contributing to the high cost of polyurethane-cured track beds.

Thirdly, polyurethane-cured track beds constructed using on-site pouring methods exhibit good maintainability when dealing with issues like foundation settlement. However, they still present relatively challenging maintenance issues in situations like foundation heaving.

5. Advantages and suggested parameters of prefabricated polyurethane-cured track beds

Factory-based prefabrication of polyurethane-cured track beds, followed by modular construction on-site, can lead to a reduction in overall costs (more than 30% lower compared to cast-in-situ polyurethane-cured track beds), improvement in construction quality, and enhanced maintainability of the structure (enabling unit modular repairs).

Experimental studies have determined that prefabricated polyurethane cured track beds meet the requirements of the "High-Speed Railway Design Specifications," indicating that the prefabricated polyurethane cured track bed structures possess adequate stability [4]. Prefabricated modular polyurethane cured track beds do not require routine maintenance and repair, offer good elasticity, and the section test results demonstrate that the stability and safety of operations are up to standard. This structure has a broad application prospect, particularly in sections with poor substructures or where routine maintenance is challenging.

As a novel track structure, the dimensions and density of prefabricated polyurethane-cured track beds can be precisely controlled during the preparation stage, helping to reduce production costs and extend the service life of the track bed. The thickness of polyurethane-cured track bed specimens is positively correlated with the amplitude of dynamic displacement. Although thinner cured track beds exhibit less residual deformation under load, their elasticity is lower, which is disadvantageous in attenuating intense upper train loads. Therefore, for lines with freight operations, the thickness of polyurethane-cured track beds should not be too small. The supporting stiffness of the track bed is negatively correlated with the thickness of the polyurethane-cured track bed beneath the sleeper. If the polyurethane track bed is too thick, it can lead to low stiffness and significant deformation during operation. Considering all factors, the thickness of prefabricated polyurethane-cured track beds for mixed passenger and freight railways should be between 28 and 32 cm. For easier fabrication, the recommended design thickness for mixed passenger and freight railway prefabricated polyurethane-cured track beds is set at 30 cm [5].

As the density, tensile strength, tear strength, and compressive strength of the polyurethane curing increase, the elongation at break first increases and then decreases, reaching a maximum at a density of 137 kg/m^3. The damping performance of polyurethane curing materials is linearly and positively correlated with the damping performance of their consolidated form. The damping performance of polyurethane curing materials is negatively correlated to the number of open-cell bubbles within the material. As the density of polyurethane curing material decreases, the number of open-cell bubbles in the material increases, enhancing energy absorption and improving damping effects. Considering both mechanical and damping properties, the ideal density of polyurethane curing materials should be between 140 and 170 kg/m^3 [6].

Disclosure statement

The author declares no conflict of interest.

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The Determination Method of Product Engineering Features Based on Linguistic Variables

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Abstract: To overcome the problem of imprecise and unclear information in the development of quality functions, a method for determining the priority of engineering features based on mixed linguistic variables is proposed. First, the evaluation member uses the determined linguistic variable to give the correlation strength evaluation matrix of customer requirements and engineering features. Secondly, the relative importance of the evaluation member and customer requirements are aggregated. Finally, the priority of engineering features is obtained by calculating the deviation. The feasibility and practicability of this method are proven by taking the design of a new product of a long bag low-pressure pulse dust collector as an example.

Keywords: Quality function deployment; Engineering features; Linguistic variable; Priority ratings

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1. Introduction

The issue of using limited resources to design and produce products that reflect customer needs in a shorter period has become the bottleneck of the long-term development of enterprises. In this case, a new product development and design method, Quality function deployment (QFD), is widely used in many industries. QFD is a systematic method to transform customer requirements into engineering features of product development and design [1]. QFD helps research and development technicians determine the main engineering features that should be prioritized for resource investment and how to set the target value of engineering features.

The house of quality is the core tool of QFD, which can systematically demonstrate the relationship between engineering features and customer needs in a three-dimensional manner [2]. Prioritizing engineering features is a key step in building a house of quality. Research and development departments need to have a deep understanding of the engineering features of new products, but due to resource constraints such as time, budget, and technology, it is impossible to take all engineering features into account. Therefore, the determination of engineering feature priority has very important theoretical and practical significance.

The process of determining the priority of engineering features in product planning involves a lot of human judgment, and there are more subjective and fuzzy factors. In fact, customers have many demands on products, and some customer requirements may be related to multiple engineering features. Conversely, the design of a certain engineering feature will also affect multiple customer requirements. At present, most methods to convert customer requirements into engineering features are qualitative. The information obtained in the process of product design is usually limited, especially when designing a new product, the error is generally relatively large, resulting in the inevitable fuzziness in the evaluation process. Such factors increase the fuzziness in determining the priority of engineering features, and selecting an appropriate decision-making method becomes the problem to be solved in this paper.

A simple digital scale can be used to represent the relationship between engineering features and customer needs[3], but it is too subjective and arbitrary to reflect the fuzziness of the information environment. To accurately evaluate the uncertainty in the priority degree of engineering features, fuzzy theory was introduced to determine the priority degree of engineering features [4]. While the fuzzy theory has some advantages over the digital scaling method, the membership function of evaluation members must be determined when using fuzzy theory, and the type of fuzzy number (triangle or bell shape) is selected according to experience, so it may be less reliable [5].

In the actual planning process, it is not easy for the evaluation members to give accurate judgments. To better reflect the fuzziness of the evaluation object, linguistic variables become the preferred form of information. The method proposed considers the different assessment objects. If accurate assessment information can be obtained easily, the determined linguistic variables will be more applicable, which facilitates the subsequent decision-making process. If accurate assessment information is difficult to obtain, uncertain linguistic variables will be used to avoid the loss of assessment information.

2. The engineering features prioritization method

The determination of the priority of engineering features is the key step in the construction of the house of quality in enterprise product planning, and the reasonable determination of the priority of engineering features has a direct impact on the subsequent construction of the house of quality. The members involved in the evaluation of engineering features come from different fields and have different understandings of different evaluation objects, so they will choose their preferred linguistic variables in the evaluation process.

Step 1: The company invites members of relevant departments to form a QFD team to obtain customer requirements based on research information and determine the corresponding engineering features. The relative importance of members is determined by the compromise voting method.

Step 2: To determine the priority of engineering features, it is necessary to analyze the correlation between customer needs and engineering features. In this process, it is difficult to give accurate evaluation information due to the differences in knowledge structure, work experience, and values among the evaluation members. Therefore, linguistic variables are selected for evaluation and the correlation strength evaluation matrix is constructed accordingly.

Step 3: By aggregating the relative importance of assessment members and corresponding linguistic variables, Equation (1) is used to obtain comprehensive linguistic assessment information, and then a group assessment matrix of association strength is constructed.

$$mre_{ij} = \rho_1 fe^1{}_{ij} \oplus \rho_2 fe^2{}_{ij} \oplus \ldots \oplus \rho_L fe^L{}_{ij} \quad (1)$$

Step 4: By aggregating the final importance of customer needs with comprehensive linguistic evaluation information, the linguistic variables of the priority of various engineering features are obtained by Equation (2), and the priority order of engineering features can be determined accordingly.

$$FS_{EC_j} = gir_1 mre_{1j} \oplus gir_2 mre_{2j} \oplus \ldots \oplus gir_M mre_{Mj} \quad (2)$$

Step 5: The priority of each engineering feature can be obtained by using Equation (3).

$$gfp_j = \frac{d(FS_{EC_j}, FS_{min}}{\sum_{j=1}^{N\sum} d(FS_{EC_j}, FS_{min}} \quad (3)$$

In view of the complexity of the actual situation and the advantages of linguistic variables, this paper proposes a method for determining the priority based on linguistic variables. This method has the following characteristics: Firstly, it allows for a more comprehensive evaluation of the correlation strength of engineering features and customer needs given by members. There can be a positive correlation, no correlation, or a negative correlation between customer needs and engineering features, which ensures the rationality of the conclusion. Secondly, the weight of each evaluation member is fully considered when the linguistic variables are collected, which prevents biases and ensures the fairness of the evaluation information.

3. Application examples

Company A is a dust collector manufacturer in western China, and LMC long bag low-pressure pulse dust collector is its leading product, which is not only used in the traditional cement industry, but also in the electric power, chemical, metallurgy, steel, and other industries. The company faced less competition when it was first established. However, in recent years, similar products have emerged and customers have become more particular about their needs, which have greatly affected the company's market share. To retain its position in the market, the company decided to innovate products and reflect customer needs into their products. The company introduced the QFD method as an important strategic means to maintain and enhance its product competitive advantage.

Step 1: The project leader invited 5 members to form a QFD evaluation team. They were tasked to select customer requirements and determine the priority of engineering features. The team was composed of 2 members from the research and development department, 2 members from the production department, and 1 member from the marketing department. In the early stage of the new product design, the QFD team determined the customer needs in the house of quality through a questionnaire survey and group discussions. The customer needs were mainly as follows: efficient dust removal, low energy consumption, easy operation and maintenance, high stability and reliability, small space utilization, good performance, and long service life of filter bag and pulse valve. The technical department of the enterprise configured the engineering features the relevant engineering features are treatment air volume, filter bag performance, total filter area, air leakage rate, total equipment weight, bag cage structure, and dust concentration at the outlet. The project leader invited 6 customer representatives from the target market to form an assessment team for the determination of demand priority. The person in charge explained the content of the project and the tasks that the members were required to complete. Each evaluation member voted using linguistic variables, and the importance and competitiveness of customer requirement by the customer representatives. TOPSIS thought was introduced to determine the basic importance and competitiveness of each customer requirements, and the importance of each customer requirement was obtained as follows:

GIR = (0.256, 0.048, 0.029, 0.079, 0.169, 0.348, 0.071).

Step 2: In the process of determining the initial importance of engineering features, due to the differences in knowledge structure and work experience, the linguistic variables were directly used to evaluate the correlation between engineering features and customer needs, and evaluation matrices of strength of association was built, which are shown in **Tables 1–5**.

Table 1. Evaluation matrix of strength of association between customer requirements and engineering features given by ES_1

	CR_1	**CR_2**	**CR_3**	**CR_4**	**CR_5**	**CR_6**	**CR_7**
EC_1	$FS_{4/3}$	$FS_{1/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	$FS_{4/3}$
EC_3	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-4/3}$	$FS_{1/3}$	$FS_{1/3}$
EC_4	$FS_{4/3}$	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_5	$FS_{4/3}$	$FS_{4/3}$	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{-4/3}$	FS_0	FS_0
EC_6	$FS_{4/3}$	FS_3	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$	$FS_{1/3}$	$FS_{4/3}$
EC_7	FS_3	FS_3	FS_0	FS_0	FS_0	$FS_{1/3}$	FS_0

Table 2. Evaluation matrix of strength of association between customer requirements and engineering features given by ES_2

	CR_1	**CR_2**	**CR_3**	**CR_4**	**CR_5**	**CR_6**	**CR_7**
EC_1	FS_3	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	$FS_{1/3}$	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	$FS_{4/3}$
EC_3	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	$FS_{1/3}$
EC_4	$FS_{4/3}$	$FS_{4/3}$	FS_0	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$
EC_5	$FS_{4/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-4/3}$	FS_0	FS_0
EC_6	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	FS_3	$FS_{1/3}$	$FS_{1/3}$	$FS_{4/3}$
EC_7	$FS_{4/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{4/3}$	FS_0

Table 3. Evaluation matrix of strength of evaluation between customer requirements and engineering features given by ES_3

	CR_1	**CR_2**	**CR_3**	**CR_4**	**CR_5**	**CR_6**	**CR_7**
EC_1	$FS_{4/3}$	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	FS_3
EC_3	$FS_{4/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$
EC_4	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_5	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	FS_0	FS_0
EC_6	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	FS_3	$FS_{1/3}$	FS_3	$FS_{4/3}$
EC_7	$FS_{4/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{4/3}$	FS_0

Table 4. Evaluation matrix of strength of evaluation between customer requirements and engineering features given by ES_4

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6	CR_7
EC_1	FS_3	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{1/3}$	FS_3
EC_3	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{4/3}$
EC_4	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{1/3}$	FS_0
EC_5	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	FS_0	FS_0	FS_0
EC_6	$FS_{4/3}$	$FS_{4/3}$	$FS_{-4/3}$	$FS_{4/3}$	$FS_{1/3}$	FS_3	$FS_{1/3}$
EC_7	$FS_{1/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{1/3}$	FS_0

Table 5. Evaluation matrix of strength of association between customer requirements and engineering features given by ES_5

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6	CR_7
EC_1	FS_3	$FS_{1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	FS_0	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{4/3}$	FS_3
EC_3	$FS_{4/3}$	$FS_{4/3}$	$FS_{-4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$
EC_4	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{-4/3}$	FS_0	$FS_{1/3}$	FS_0
EC_5	$FS_{1/3}$	$FS_{4/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	FS_0	FS_0
EC_6	$FS_{4/3}$	$FS_{1/3}$	$FS_{-1/3}$	$FS_{4/3}$	$FS_{1/3}$	FS_3	$FS_{1/3}$
EC_7	$FS_{1/3}$	FS_3	FS_0	FS_0	FS_0	$FS_{4/3}$	FS_0

Step 3: According to the compromise voting method, the relative importance of the 5 evaluation members was found to be . The strength of association evaluation information given by the evaluation members was aggregated using Equation (1) to obtain the group evaluation matrix of the QFD team (**Table 6**).

Table 6. Group evaluation matrix of strength of association between customer requirements and engineering features

	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6	CR_7
EC_1	$FS_{2.432}$	$FS_{0.735}$	$FS_{-0.129}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{4/3}$	FS_0
EC_2	$FS_{0.075}$	FS_0	$FS_{1/3}$	$FS_{4/3}$	FS_0	$FS_{0.496}$	$FS_{2.270}$
EC_3	$FS_{0.895}$	$FS_{1.141}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{-1/3}$	$FS_{0.895}$	$FS_{0.978}$
EC_4	$FS_{0.771}$	$FS_{4/3}$	FS_0	$FS_{-0.928}$	$FS_{-0.279}$	$FS_{0.558}$	FS_0
EC_5	$FS_{4/3}$	$FS_{0.934}$	$FS_{-0.546}$	$FS_{-1/3}$	$FS_{-0.963}$	FS_0	FS_0
EC_6	$FS_{1.108}$	$FS_{1.185}$	$FS_{-1/3}$	$FS_{1.980}$	$FS_{1/3}$	$FS_{0.895}$	$FS_{0.978}$
EC_7	$FS_{2.280}$	FS_3	FS_0	FS_0	FS_0	$FS_{0.928}$	FS_0

Step 4: The group evaluation information of the priority of each engineering feature was obtained using Equation (2) as follows:

$FS_{EC1} = FS_{1.036,} FS_{EC2} = FS_{0.468,} FS_{EC3} = FS_{0.572,} FS_{EC4} = FS_{0.335,} FS_{EC5} = FS_{0.181,} FS_{EC6} = FS_{0.923,} FS_{EC7} = FS_{1.051.}$

Step 5: The priority of each engineering characteristic was obtained through Equation (3) as follows:

$gfp_1 = 0.157$, $gfp_2 = 0.136$, $gfp_3 = 0.140$, $gfp_4 = 0.130$, $gfp_5 = 0.124$, $gfp_6 = 0.153$, $gfp_7 = 0.158$.

The order of priority of engineering features was $EC_7 > EC_1 > EC_6 > EC_3 > EC_2 > EC_4 > EC_5$. The dust concentration at the outlet and the treatment air volume had a greater impact on customer requirements. Therefore, these two features should be prioritized during the product development and planning stage.

5. Conclusion

The method of determining the priorities of engineering features proposed in this paper facilitated the collection of accurate information on the correlation strength between customer requirements and engineering features. With this method, the evaluation members within the enterprise had a better understanding of engineering features, and thus, the determined linguistic variables were used to obtain the priority of engineering features by aggregating the relative importance of the evaluation members and the priority of customer requirements. This method was proven to be feasible by using it to determine the priority of each feature of the dust collector of Company A.

Disclosure statement

The author declares no conflict of interest.

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Analysis of Roadbed Splicing at Hub Interchanges

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Abstract: This article discusses the roadbed splicing for hub interchanges. The article starts with a description of the characteristics of junction roadbed splicing. The application of splicing technology is explained using a subgrade splicing scheme of a project. Roadbed splicing involves stepwise excavation and preparative measures like surface cleaning and backfilling. This article serves to provide a valuable reference for road and bridge construction and improve the quality of China's road and bridge projects, so as to achieve sustainable development of the road and bridge engineering industry.

Keywords: Hub interchange; Roadbed splicing; Construction preparation; Stepwise excavation; Roadbed filling

Online publication: February 26, 2024

1. Introduction

Mastering roadbed splicing of hub interchanges is of great significance for ensuring the construction quality of hub interchanges, improving traffic efficiency, and ensuring traffic safety. Roadbed splicing is an important part of hub interchange reconstruction that involves many aspects such as the bond between different materials, the technologies used, and the formulation of construction plans. By mastering hub interchange roadbed splicing, problems like loosening, cracking, damage, horizontal imbalance, and other problems can be prevented. reduce the incidence of traffic accidents, and at the same time provide citizens with a better travel experience.

2. Characteristics of hub interchange roadbed splicing project

Based on the records of many hub interchange projects, there are several common characteristics of these kinds of projects.

(1) Complex road surface shape

The pavement shape of the hub interchange is complex and ever-changing, with a heavy traffic flow. It must adapt to different vehicle speeds, vehicle models, and road conditions. The splicing project should provide a smooth and safe traveling experience. Therefore, there are high requirements for roadbed splicing solutions and materials.

(2) Diversified material structure

A variety of composite materials are needed to splice the roadbed of hub interchanges, such as asphalt

concrete, reinforced concrete, rubber, etc. It is also necessary to consider the process of connecting different materials to each other, such as welding, fixing, slotting, etc., to ensure that the parts are connected properly [1].

(3) High quality requirements

As an important node of urban transportation, quality is of utmost importance in the reconstruction or renovation of interchange hubs. The end product of roadbed splicing should be both functional and aesthetically pleasing. It is necessary to design the construction plan in advance and allocate a suitable number of construction personnel and equipment to ensure construction quality and progress while ensuring safety [2].

(4) Reasonable technical solution requirements

It is necessary to formulate a suitable plan for the roadbed splicing at hub interchanges. Methods such as natural transition, gradual transition, or artificial transition can be adopted according to the terrain and soil conditions. Technical solutions should be formulated based on the actual conditions and advanced technologies should be compo

(5) Refined construction management requirements

Interchange transformation projects are usually large-scale, time-consuming, and complex. Strict specifications need to be formulated for every link and detail in the construction process, including construction design, material selection, on-site construction, etc. Factors that need to be considered in construction management are time, cost, quality, and other factors [3].

3. Research on construction technology of subgrade splicing for hub interchanges

3.1. Project overview

In order to objectively grasp the hub interchange roadbed splicing construction technology, this article uses the H hub Interchange Project (Project H) as an example to discuss the application of roadbed splicing in interchange hubs.

H is located at the transportation hub of a certain city, connecting the city center to surrounding areas. It is an important transportation hub for the upper and lower urban areas of the city. The project covers an area of approximately 35,000 square meters, including 9 ramps and 4 bridges, with a designed traffic flow of approximately 5,000 vehicles per hour. Project H was designed based on factors such as the terrain and traffic flow of the area. Two different materials were selected to form the roadbed: reinforced concrete roadbed and asphalt concrete pavement. “Asphalt pouring + reinforced concrete + asphalt or rubber” was adopted to ensure the quality of the end product and the smoothness of the surface.

3.2. Roadbed splicing plan

A reasonable splicing scheme can not only ensure the traffic operation efficiency of hub interchanges but also improve the safety and reliability of its roads [4]. During the formulation of the roadbed splicing plan, the main points are the rationality of the road alignment, material selection and splicing, construction quality control, and environmental protection.

3.2.1. Road alignment

Due to the busy traffic and complex road conditions at the H Hub Interchange, the rationality of the route directly affects the stability and smoothness of the entire road surface. Therefore, the roadbed splicing scheme was designed collaboratively by the construction and design units. This approach ensured that the road

alignment was considered and that sharp turns, steep slopes, complex intersections, and small turning radius, were avoided to the greatest extent [5].

3.2.2. Material selection and material splicing

The selection of base materials is the key to ensuring the quality of hub interchange roads. Common materials for roadbed construction include reinforced concrete, asphalt concrete, cement, etc. During material selection, it is essential to consider factors such as traffic flow and the road's surrounding environment. At the same time, the junction of different materials must be tightly paved, and strict construction management is required [6]. In this project, the roadbed was filled with natural gravel materials, and geogrids were paved at the same time. The base and roadbed were laid uniformly to increase the integrity of the old and new roadbeds even out the natural gravel roadbed (**Figure 1**).



Figure 1. Schematic diagram of geogrid laying on roadbed

3.2.3. Construction management and quality control

Good construction management can effectively improve construction efficiency and quality and ensure road safety and stability. Construction management and quality control were emphasized in Project H. Technical training, construction material selection, transportation management, and construction supervision were all documented clearly to ensure the road conditions meet the design requirements.

3.2.4. Environmental protection

Environmental protection is one of the key points in the construction of road projects. During the construction of Project H, all pollutants involved in the construction process were supervised in accordance with relevant laws and regulations to minimize the impact on the ecological environment and living environment around the hub interchange [7].

3.3. Stepwise excavation and construction plan

In order to effectively improve the overall stability of the new and old roadbed, before filling, the construction unit excavated the old roadbed slope into a step shape and then widened and heightened the first step to reach 300 cm wide and 100 cm high. The subsequent upper steps were 200 cm wide and 100 cm high. At the same time, the construction unit removed the over-excavation and backfilling of the old road surface and installed geotechnical barriers.

3.4. Preparation for roadbed splicing construction

Hub interchange roadbed splicing is a complex and systematic process, so sufficient preparations are needed before construction to ensure high-quality and smooth construction. In Project H, proper preparations were made before splicing construction, which is summarized below.

(1) Conductor point retest

The conductor points in the design were retested and accurately arranged at the project site before construction to ensure consistency between the design and the actual construction site [8].

(2) Placing the total station at the edge

After laying out the wires, a total station was used to trace points at specified intervals outside the reinforced concrete subgrade part of the road to pave the way for subsequent construction.

(3) Roadbed surface retest

The roadbed surface was retested to determine its height difference and flatness to ensure the construction quality.

(4) Base soil testing

Before laying the roadbed, foundation testing was conducted to ensure that the roadbed could meet the design requirements and that soil treatment could be carried out in advance.

(5) Setting up warning signs

Warning signs were set up at the construction site to ensure the safety of the passersby and the boundaries of the site were set to prevent outsiders from intruding on the construction area [9].

(6) Technical briefings

The construction personnel were given a technical briefing on the overall process, methods, and requirements of the project.

3.5. Surface cleaning and backfilling

The smoothness and quality of the roadbed are essential in roadbed splicing projects. Surface cleaning and backfilling are important links to these kinds of projects. In Project H, before the construction started, debris such as weeds and branches within the base area were removed. Besides, in order to ensure the smoothness and strength of the roadbed, humus soil and topsoil were removed. By doing so, a new roadbed could be placed evenly.

Secondly, the scope of the cleared site was clearly defined, and ensured that it was within the designed scope of the roadbed to avoid shifts in the center of gravity. After completing the surface cleaning, the road pavement was compacted to ensure the smoothness and strength of the road surface.

Areas with high water content were excavated and dried. (1) The base with higher water content was dug out to increase the surface area of the wet area. (2) Drying: The dug base was exposed to the sun to allow the water to evaporate to achieve the desired water content. (3) Trimming: The dried base was trimmed to meet the requirements of roadbed design. (4) Backfill: The modified base was backfilled to the original height of the road and compacted to ensure the smoothness and quality of the roadbed.

3.6. Stepwise excavation

The slope of the old roadbed slope was cleared before excavation. After cleaning the slope, each excavation line was marked accurately. After excavating and joining the steps at the base of the roadbed, the height and position of the steps were determined according to the fill height of the roadbed. The step surface was defined as a step when the distance between it and the base surface of the subgrade was less than 130 centimeters. If it exceeded 130 centimeters, it was divided into two step heights: 100 centimeters and greater than 130 centimeters. The

specific excavation position was set at 30 centimeters outward from the inner edge of the old road's hard shoulder, with a step height of 80 centimeters.

In addition, the excavation was immediately halted when a large-scale soil displacement was discovered and the reason behind the displacement was analyzed. Corresponding measures were formulated to avoid landslides. Besides steel-wood support was installed to protect the back of the old roadbed structure and the roadbed was filled with gravel materials.

3.7. Roadbed filling

3.7.1. Filling material selection

The materials used for roadbed filling mainly include soil, stone, bricks, etc. The materials were selected based on comprehensive considerations of the usage requirements, site conditions, and cost. Since Project H was constructed in autumn, the air was dry and the soil was stable, so ground gravel was used as filling material to improve the stability and drainage of the filling layer.

3.7.2. On-site investigation

On-site investigation and measurements are necessary before the construction starts to determine the thickness and slope of the filling layer. The measurements include the height and width of the roadbed. In order to improve construction accuracy, the construction unit arranged for construction personnel to use a total station for stakeout.

3.7.3. Paving

In Project H, after the materials were laid, the bottom of the roadbed was cleaned to ensure that the bottom of the filling layer was smooth and free of debris and water puddles. Besides, in order to increase the stability of the filling layer, the bottom of the roadbed was compacted. The roadbed was paved evenly and lightly compacted. Subsequently, it was leveled and adjusted to achieve the desired thickness and slope. After the paving was completed, moderate compaction was carried out to improve the stability and density of the roadbed.

3.7.4. Adjusting the water content

Moderate water content can increase the stability and fluidity of the filling layer, but excessive water content will cause damage to the roadbed. In order to ensure that the water content is within the acceptable range, the test block method was employed to measure the water content. The optimum water content was approximately 2% level. The water content was adjusted according to the acceptable range to ensure the quality and stability of the filling layer. For areas where the water content is less than the optimum level, sprinkler trucks were used to wet the area.

3.7.5. Filling and rolling

A rolling plan and the required equipment were determined based on the test section before filling and rolling the roadbed. A road roller was used for rolling. In the rolling stage, the maximum driving speed of the equipment was ≤ 4km/h. Straight sections were rolled from the edge of the widened roadbed towards the joint of the old roadbed from low to high [10]. In addition, the roller was equipped with a half-width wheel, and rolling was performed from slow to fast and light to heavy. The degree of compaction was increased at the junction of the new and old roadbed. In areas such as steps and blind spots, heavy-duty steel rollers and small impact compactors were utilized for compaction.

3.8. Dynamic compaction and treatment of the roadbed

During the construction phase of the roadbed splicing at the interchange, dynamic compaction was carried out on the top of the roadbed. This was done to prevent settlement of the new roadbed of Project H and to avoid longitudinal cracks at the junction of the new and old roadbeds.

During the operation stage, the joint between the old and new roadbed was treated to ensure a smooth surface. Debris, gravel, and other materials were cleared, any possible gaps were filled, and stains adhering to the subgrade were cleaned. The top of the roadbed was then compacted. During the construction period, the ramming rhythm and ramming speed were strictly controlled to ensure consistency and uniformity of tamping. It is necessary to avoid compaction at a pace that is too rapid, which could lead to insufficient compaction or cause cracking in the new and old roadbeds.

4. Conclusion

In summary, this article takes Project H as an example to analyze roadbed splicing at hub interchanges. There are five main characteristics of these kinds of projects: complex road surface, diversified material structure, high standards, the need for reasonable technical solutions, and the need for refined construction management. This article serves to provide ideas on improving the quality of roadbed splicing at interchanges by analyzing Project H, so as to improve the safety of highways.

Disclosure statement

The author declares no conflict of interest.

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A Review of Artificial Waterfalls in Gardens

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Abstract: When artificial waterfalls are built in gardens, leaves from trees or vegetation often fall into the water storage pool and block the pipelines, requiring regular cleaning of pipelines. This not only increases the manpower needed for maintenance but also disrupts the use of the waterfalls. Therefore, it is necessary to design a new type of artificial waterfall that is suitable for gardens. The waterfall should incorporate features that make cleaning easier, including filter plates and water funnels to prevent clogging caused by fallen leaves and debris.

Keywords: Intelligence; Efficiency improvement; Transportation pipeline; Technical artificial waterfall

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1. Introduction

Gardens refer to specially cultivated natural landscapes and recreational areas. Gardens are divided into two categories: royal and private gardens, both renowned for their unique styles [1]. Within a defined geographical area, engineering technology, and artistic techniques, such as terrain manipulation (including mountain construction, stone stacking, and water management), diverse planting of trees and flowers, construction of buildings, and establishment of walkways are employed to craft a picturesque natural environment. Such recreational spaces are commonly referred to as gardens [2].

As the demand for a better quality of life increases, garden landscape construction has become an important part of urban construction. Therefore, it is essential to design and build excellent landscapes. Traditional garden architecture plays a unique role in traditional Chinese architecture. However, for gardens with artificial waterfalls, leaves from trees or plants often fall into the water storage tank, causing pipeline blockage. Therefore, the pipelines will need to be cleaned regularly, causing much inconvenience for the staff [3].

2. Status of artificial waterfalls

Artificial waterfalls serve as distinctive landscape features, enhancing the natural beauty and aesthetic appeal of gardens, parks, commercial properties, and various other settings. Their presence captivates attention and generates interest. With the rising societal inclination towards leisure, entertainment, and environmental consciousness, the demand for artificial waterfalls is steadily increasing, leading to continuous growth in the

market for such installations. Urbanization, while progressing rapidly, has resulted in diminishing public and private spaces within cities, intensifying people's desire for natural beauty. Consequently, artificial waterfalls have garnered significant market interest as they offer a means to cultivate natural beauty within constrained urban environments [4].

The continuous development of science and technology has led to the evolution of artificial waterfall design and manufacture, making the visual effects of waterfalls more realistic and diverse [5]. Besides, the emergence of new materials opened up more possibilities in artificial waterfall construction. The development of artificial waterfalls is also largely affected by environmental awareness. With an increasing demand for environmental friendliness and sustainability, more emphasis has been placed on energy saving, emission reduction, and rational use of water resources in waterfall design and construction [6]. Designing a new type of artificial waterfall is one of the solutions to the problems associated with artificial waterfall utilization.

3. Market prospects

Artificial waterfalls can provide visual and auditory pleasure, making them popular spots among tourists. As the demand for tourism and leisure activities rises, so does the popularity of artificial waterfalls. Secondly, with the continuous acceleration of urbanization, green spaces and landscapes within cities have become increasingly important. Artificial waterfalls play a crucial role in enhancing the aesthetic appeal and greenery of urban areas, including parks, squares, and communities. Their presence contributes to the overall comfort and satisfaction of city dwellers. Thirdly, artificial waterfalls provide fresh air and a soothing environment, which contribute to improving one's physical and mental health [7]. With the growing consciousness surrounding health and environmental preservation, there is a parallel increase in demand for landscape architecture that offers both natural environments and health benefits. Moreover, ongoing technological advancements have led to a gradual reduction in the production and maintenance costs associated with artificial waterfalls. This reduction in costs opens up new possibilities in design and effects. This will attract more designers and developers to adopt artificial waterfalls as part of their landscape architecture, further promoting market development. While artificial waterfalls hold great promise, the competitive market demands that manufacturers and designers continuously innovate and improve product quality to meet customer needs. Besides, the construction of the waterfalls should align with the principles of environmental friendliness and sustainable development.

4. Project features

To fulfill the demand for a better quality of life, a novel type of artificial waterfall was designed. This type of artificial waterfall offers several advantages.

The project is divided into multiple horizontal and vertical sections to minimize the impact of the water flow, allowing visitors to better appreciate the waterfall's beauty. The design incorporates sloping surfaces, guiding rainwater to cascade down from the slope and slide to the ground. At the same time, to prevent rainwater from entering the storage tank, a filter is installed at the water outlet. The pump is designed in a way that allows the recycling of the water in the storage tank, which greatly reduces the workload of the staff. Furthermore, filter plates and filters are installed to prevent debris from entering the storage tank. This feature helps prevent water accumulation in the reservoir. Additionally, a leak-proof plate, adjustable by a spring mechanism, is installed at the reservoir's bottom to effectively prevent clogging. The protective cage is assembled in the tank using a four-part process, facilitating easy disassembly and cleaning for workers.

5. Product description

(1) People-oriented

The pipelines of artificial waterfalls in gardens are often blocked because leaves and debris from the surrounding plants fall into the water storage pool, so the pool will have to be cleaned regularly, which is a problem [9]. Most storage pools in the market can only be cleaned manually, which is time-consuming, labor-intensive, and unsafe [10]. Therefore, we designed a new type of artificial waterfall that enables easy cleaning.

(2) Description of the new artificial waterfall

The artificial waterfall consists of a waterfall platform and a storage tank. Inside the storage tank, a delivery pipe is enclosed within a protective cage, which includes multiple connecting plates secured by waterproof bolts. These bolts are inserted into waterproof nuts fixed in a fixing plate. A cover plate is affixed to the upper end of the protective cage, connected to its side wall through screws. The fixing plate is positioned within the water tank and securely attached to its inner wall. The upper end of the protective cage is linked to a water conduit, with a gas pipe inserted into it. One end of the gas pipe connects to the water outlet of the water pump, while the other end connects to the water storage tank. The water pump is electrically connected to an external power supply via wires. Inside the tank, a baffle is installed, connected to an electric telescopic rod, which in turn is linked to a rope reel housing a wound rope. Grooves are incorporated into the waterfall platform, which houses the control systems.

6. Conclusion

The new type of artificial waterfall proposed in this paper has broad market prospects, especially in the tourism and entertainment industries. Artificial waterfalls improve the aesthetic appeal and greenery of scenic spots, parks, communities, etc., making city dwellers more comfortable and satisfied. As design and production technology for artificial waterfalls continues to evolve, costs are gradually decreasing, opening up more innovative possibilities. Through long-term analysis and research on the artificial waterfall market, our team has gained an understanding of people's landscape preferences. In response, we designed this intelligent, technological, and innovative landscape artificial waterfall to cater to these needs and enhance their quality of life. As society progresses, there is a growing emphasis on intelligence and humanity in people's lives, with a focus on practicality and innovation. Therefore, the design of a product has to be centered around people's needs, which also applies to designing artificial waterfalls.

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(3) Chongqing Institute of Engineering School-Level Project: Research on Urban Waterfront Landscape Design Based on The Concept of River Ecological Restoration – Taking the Chongqing Institute of Technology Section Along the Huaxi River as an Example (No.: 2022xskz02)

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Analysis of Safety Assessment and Testing of Heavy Traffic Vehicles on Old Bridges Without Data

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Abstract: This article presents a real-life project that aimed to evaluate the safety of traffic vehicles on old bridges without any prior data. The project involved various safety inspections, including conventional, static, and dynamic load inspections and safety assessments. After conducting these tests, it was concluded that the structure of the old bridge is relatively safe, with only a few bumps. The bridge could function normally following appropriate treatment. The analysis provides valuable insights into the assessment of the quality and safety of such bridges to ensure the safe driving of heavy vehicles.

Keywords: Old bridge; Absence of data; Heavy vehicles; Safety inspection; Safety assessment

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1. Introduction

The design and construction data for some old bridges may no longer be available. Therefore, to ensure the safety of driving across the bridge, a safety assessment needs to be conducted through a few tests [1]. In this way, the operation, the durability, and the safety of the bridge can be guaranteed

2. Project overview

The project that will be discussed in this paper is an old four-span supported bridge project. The design and completion date of the project could no longer be found. There was only a nameplate on the bridgehead that stated that it was constructed in 1991. Field measurements showed that each span of the old bridge was 16 m, and the width of the bridge deck was 8 m. There was an ongoing building construction near the old bridge, so it had to withstand heavy vehicles like flatbed trucks and dump trucks. The traffic requirements dictated that 100-ton flatbed trucks should be able to pass independently at normal speeds; the 100-ton flatbed truck should be able to pass independently along the center line of the bridge at a normal speed; the 40-ton dump truck should be able to pull over and cross the bridge independently at a normal speed; the 15-ton unloaded dump truck

should be able to return at normal speed and together with the dump truck. However, since the bridge had not been tested for the safe passage of heavy vehicles, the relevant units decided to inspect and evaluate the safety of the bridge based on the requirements mentioned. This article is an analysis of its safety tests and assessment.

3. Heavy vehicle safety assessment, testing, and analysis

3.1. Routine testing

Routine testing is the most basic form of test when it comes to safety testing. It involves an observation of the bridge's appearance, bridge deck system inspection, superstructure inspection, bridge support inspection, substructure inspection, and inspection of other ancillary equipment, etc [2]. It was observed that the main beams of each span in the old bridge project were all made of C40 concrete, and the piers were all made of C35 concrete. Its main load-bearing components were all in good condition. However, there were some noticeable bumps at the 0# abutment and 4# abutment. If a load-carrying vehicle were to pass over these areas, it would subject the main beams of spans 1# and 4# to significant impacts. This could potentially lead to damage or further exacerbate existing damage, thereby compromising the safety and durability of the overall bridge structure. Therefore, the bumps had to be flattened to make the overall bridge deck smoother [3].

3.2. Static load test

Static load test is a crucial part of bridge safety testing [4]. In this test, a 43t truck was stationed on the right and left sides of the bridge. The first test conducted was the deflection test. Two deflection detection points were positioned on the left side of the bridge, namely A1 and A2, along with four deflection detection points on the mid-span section, namely B1, B2, B3, and B4. Additionally, two deflection detection points were set on the right section of the bridge, namely C1 and C2 [5]. The result of the deflection test is shown in **Table 1**.

Table 1. Deflection detection results

Serial number	Project	Deflection test results (unit: mm)							
		A1	A2	B1	B2	B3	B4	C1	C2
1	Level 1 load	0.6	0.3	4.2	4.0	3.1	2.3	0.4	0.0
2	Level 2 load	1.0	0.5	7.5	7.2	5.8	5.2	0.7	0.7
3	Unloading	0.4	0.2	0.1	0.5	0.2	0.7	0.3	0.2
4	Full load elasticity with support	0.7	0.3	7.4	6.8	5.5	4.4	0.5	0.5
5	Full load elasticity without support	-	-	7.0	6.3	5.1	3.9	-	-
6	Full load elasticity theoretical value	-	-	7.6	6.9	5.5	4.9	-	-
7	Test coefficient	-	-	0.92	0.91	0.92	0.80	-	-
8	Residual ratio	-	-	1.3%	6.9%	3.4%	13.5%	-	-

According to this project's specifications, each span beam's deflection coefficient should be between 0.7 and 1.05. The measured deflection coefficient was 0.8–0.95, which was well within the specified range. The residual ratio of each deflection point was also within 20%, which indicated that the bridge was qualified for normal operations.

The second test that was carried out was the strain test. 10 observation points were set on the supported beam's mid-span section, and the strain data of the simply supported beam at its first span under various experimental design conditions were measured. The deflection coefficient obtained at each measuring point was

measured to be 0.75–0.95, which aligned with the specifications of the project. The residual ratio at each strain point position was less than 7%, indicating that the old bridge structure could function normally. **Table 2** shows the test strain detection results in this project:

Table 2. Test span strain detection results in this project (part)

Serial number	Project	Strain detection results (unit: με)				
		Point 1	Point 2	Point 3	Point 4	Point 5
1	Level 1 load	97.6	46.3	50.4	9.4	18.2
2	Level 2 load	204.3	179.8	178.5	176.9	174.3
3	Unloading	10.1	12.5	8.9	10.4	10.8
4	Full load measurement	194.2	167.4	169.6	166.5	163.5
5	Full load theoretical value	238.0	202.1	202.1	181.7	181.7
6	Test coefficient	0.82	0.83	0.84	0.92	0.90
7	Residual ratio	4.9%	7.0%	5.0%	5.9%	6.2%

No significant lateral stress cracks were found on the old bridge structure before and during the tests. Through the static load tests, it is clear that the deflection and strain coefficients of the old bridge structure were consistent with the specifications of this project, and no lateral stress cracks were found during the test [6]. This indicated that each span in the old bridge structure could still work normally and withstand heavy vehicles on full load.

3.3. Dynamic load tests

After the static load tests, dynamic load tests were carried out. These tests ensure that the heavy vehicles can move past the bridge safely. There are two tests involved in dynamic load tests.

The first test was to measure the natural vibration frequency of the bridge without any vehicles on it [7]. The theoretical natural vibration frequency of the bridge without vehicles was calculated to be 8.8 Hz. However, the measured natural vibration frequency of the first span was 9.10Hz, that of the second span was 9.11Hz, and for the third span, it was 9.08Hz. As for the fourth span, its natural vibration frequency was recorded at 9.21Hz. Based on these results, it was clear that the actual natural vibration frequency of each span of the bridge exceeded the theoretical value, indicating that the overall stiffness of the old bridge structure is greater than the expected value, making it suitable for normal operations.

The second test involved driving a test car over the old bridge structure at various speeds to measure the vibrations experienced by the bridge under different driving conditions. This included analyzing the vibration frequency, vibration amplitude, and impact coefficient of the old bridge structure across different driving scenarios of the test car [8]. The vehicle was driven at speeds of 20 km/h and 30 km/h. Several dynamic vibration sensors were placed on the bridge deck and mid-span of each span. The vibrations of each measuring point were measured under dynamic load conditions. According to the requirements of this project, the impact coefficient of the old bridge structure should be 1.218 and below. Under the first test condition with the car driving at 20 km/h, the actual impact coefficients of the four spans of the bridge were measured as follows: for the first span, the coefficient was 1.216, for the second span, it was 1.106, for the third span, it was 1.103, and for the fourth span, it was 1.208.

Under the second test at 30 km/h, the impact coefficients were as follows: 1.231 for the first span, 1.112 for the second span, 1.115 for the third span, and 1.226 for the fourth span. Comparative analysis showed that

the impact coefficients of the second and third spans of the old bridge did not exceed the theoretical values during the two-vehicle driving tests. However, among them, the impact coefficients of the first and fourth span structures exceeded the theoretical values under the second driving condition, indicating insufficient impact resistance. Upon visual inspection of these two parts, it was found that the reason for this situation was that the first and fourth spans were uneven, which made the spans bumpy, leading to a high impact coefficient. If these problems were not addressed, the main beam structures of the first and fourth spans would gradually deteriorate due to the rapid passage of heavy traffic vehicles, compromising the durability of the overall structure and posing significant safety risks. To prevent such problems, before the old bridge structure was put into use, the bridgeheads of the first and fourth spans were leveled. This measure could effectively eliminate bumps and reduce the impact coefficient when heavy traffic vehicles are traveling rapidly [9].

3.4. Safety assessment

Based on the actual situation and theoretical analysis of the old bridge project site, traffic conditions for the 100-ton heavy-duty flatbed truck dictated that only one vehicle could pass along the center line, with its driving speed controlled at 30 km/h. For 40-ton heavy-duty dump trucks, normal driving speeds were permitted. Similarly, 15-ton unloaded dump trucks could be driven at normal driving speeds. However, in practical applications, to ensure the safety of heavy vehicle operation and enhance the durability of the bridge, the driving speed of all heavy vehicles was limited to 30 km/h [10].

According to the safety test evaluation results, the overall appearance of the bridge was satisfactory, with no noticeable issues, except for significant bumps detected at abutment 0# and abutment 4#. The static load test shows that the bridge can fully meet the independent driving needs of the 100-ton heavy-duty flatbed truck on the center line and can also meet the load-carrying requirements of the 40t dump truck when it pulls aside on the bridge and when it meets the 15-ton unloaded dump truck on the bridge. Additionally, the dynamic load test demonstrated that the second and third-span bridgeheads met the practical application requirements. However, the first and fourth spans' bridgeheads were uneven, necessitating appropriate leveling measures.

4. Conclusion

Before an old bridge is put into use for heavy vehicles, if its original design and construction information cannot be retrieved, reasonable testing methods must be conducted to evaluate its safety. These tests include routine testing, static and dynamic loads, and more. By assessing the deflection, strain, and impact coefficients of the structure under various test conditions, structural problems can be discovered and addressed in time. This approach ensures the structural integrity of the old bridge and that it meets actual transportation requirements. Additionally, it significantly prolongs the old bridge structure's service life and reduces subsequent operation and maintenance costs.

Disclosure statement

The authors declare no conflict of interest.

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Analysis of Bridge Inspection Technology for Highway Reconstruction and Expansion

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Abstract: This article focuses on bridge testing technologies in highway construction and expansion projects. It provides an overview of the inspection process for bridges in highway reconstruction and expansion projects, the main inspections, and strategies for improving the quality of inspections. Relevant units should conduct bridge inspections using appearance inspections, special inspections, and bearing capacity assessments in highway reconstruction and expansion projects. To effectively improve testing quality, relevant units should also focus on establishing and improving testing standards, strengthening material testing, and improving the overall quality of the testing personnel. This research aims to enhance the quality of highway reconstruction and expansion projects by supporting the sensible application of bridge inspection technology.

Keywords: Expressway; Reconstruction and expansion; Bridge engineering; Detection technology

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1. Introduction

In the current highway reconstruction and expansion project, bridge inspection has become an indispensable part of the work. Bridge inspection involves meticulous appearance, special inspections, and bearing capacity assessment. In this way, the overall quality and safety of bridge engineering can be guaranteed. This will benefit the construction, application, and development of bridge engineering in highway reconstruction and expansion projects.

2. Overview of highway reconstruction and expansion bridge inspection

2.1. Meeting the needs of a growing society

Through urbanization and industrialization, the number of industries and population in cities has been constantly increasing, and the number of automobiles has also shown a gradual upward trend. Under such a development model, many existing highway projects are beginning to modern actual transportation needs. To adapt to the development of today's society and meet the practical needs of highway transportation, many

highway projects need to be reconstructed and expanded [1]. In this way, we can effectively solve problems such as traffic congestion, poor road conditions, and insufficient bearing capacity that exist in traditional highway and bridge engineering applications, promote the development of the highway transportation industry, and create favorable conditions for socio-economic development.

2.2. Main ideas for renovation and expansion

The are several reconstruction and expansion ideas for bridge projects. (1) Design preparations: When designing a highway reconstruction and expansion project, the designer must do a good job in the preliminary design of the bridge project, including its beam structure, span and bearing capacity design, etc., to meet the actual reconstruction and expansion of the highway project and its subsequent application requirements. (2) Formulating a construction plan: Before formal construction, a proper construction plan should be formulated based on the type of project, including workflow, sequence of each segment, technology, and equipment used, detection technology, etc., to ensure maximum construction quality. (3) Following the construction plan strictly: The bridge should be constructed according to the design and plan, including pier construction, superstructure construction, wing wall construction, and guardrail construction, etc. (4) Quality inspection: Quality inspection is necessary after completing the construction of the bridge, including appearance inspection, special inspection, and load-bearing capacity assessment, etc., to achieve good control of construction quality and safety to meet the needs of subsequent practical applications of the overall bridge.

3. Main inspections in highway reconstruction and expansion bridge projects

Appearance inspection, special inspection, and load-bearing capacity assessment are the most important inspection contents when inspecting the bridge project. Therefore, these inspections should be carried out using proper methods.

3.1. Appearance inspection

For bridge projects in highway reconstruction and expansion projects, appearance inspection is the most basic inspection item during specific inspections. Normally, appearance inspection includes inspecting the main beams, side rails, bridge decks, etc. visually. Visual inspection are performed to look out for deformations, cracks, corrosion, or damage [2]. While visual inspection does not require advanced technology and equipment, the inspector should be experienced so that problems can be discovered and addressed in time.

3.2. Special tests

In the highway reconstruction and expansion project, relevant units and inspection technicians must also conduct special inspections to ensure the bridge project's quality.

The first test involves the inspection of physical structures. (1) Ultrasonic rebound test is used to detect the rebound value of the concrete surface of the bridge engineering structure, and the data obtained is used to calculate the concrete strength, and the calculation results are compared with the design requirements to determine if adjustments are needed. (2) Ultrasonic non-destructive testing technology is used to detect internal defects in the concrete structure.

The second step is flatness inspection. The flatness of the bridge can be inspected using a laser flatness measuring instrument. The flatness is measured based on the change between the emitted and reflected signals like speed, acceleration, and displacement. Laser flatness detectors are faster and more accurate than traditional flatness detectors.

Finally, there is dynamic experimental detection, which involves driving a test car on the bridge and measuring the inclination and strain conditions of each structural point in the bridge project, so as to determine the damping value, natural frequency, and mode shape of the bridge structure. During this process, the acceleration is set at the 1/4 span, 1/2 span, and 3/4 span positions of the bridge and Basic Data Infrastructure (BDI)-supporting data processing software is used to analyze the changes in the bridge structure when the vehicle is being driven on it, and these data will be used to determine if further optimizations are needed [3].

3.3. Bearing capacity assessment

Load-bearing capacity assessment is a key content in highway bridge reconstruction and expansion project inspection. The load-bearing capacity of the bridge is assessed through static and dynamic load tests.

(1) Static load test

The amount of load applied should be determined based on the influence line of the bridge, and the load should be placed at the most the most fragile portion of the bridge. A mobile load-tracking device is then used to track and detect the load-bearing capacity of the portion of the bridge. Subsequently, a bridge deflection detector is used to measure the deflection of each most unfavorable loading position. To ensure the accuracy of the test results, before the formal loading test is carried out, two standard loading trucks should be positioned at the test span for 20 minutes or more. This process is called transverse symmetrical preloading and control the load duration. Formal loading is performed after the preloading and the bridge structure is fully restored. Formal loading needs to be carried out in stages, and only after the deformation of the upper-level structure is relatively stable can the next stage of loading be carried out [4]. The deformation of the bridge should be less than 20% with no obvious cracks upon the completion of the last loading test.

(2) Dynamic load test

This test is mainly to detect the impact coefficient of vehicles on the bridge structure at different driving speeds, including a barrier-free driving test, vehicle jumping test, and braking test. The vehicle impact coefficient on the bridge structure can be calculated based on the test results and comparing it to a reference value. In this way, the dynamic load capacity of the overall bridge structure can be scientifically evaluated.

4. Strategies to improve inspection quality of highway reconstruction and expansion bridge projects

4.1. Establishment and improvement of testing standards

To further improve the inspection of bridge engineering structures in highway reconstruction and expansion projects, suitable inspection standards will need to be established based on the technologies used and the type of project. The establishment of standards involves several aspects. (1) The testing items and targets should be determined based on the needs of the project [5]. (2) The standard operating procedure, the parameters measured, and the maintenance of the test equipment should be well-understood. (3) The responsibilities of each staff must be clearly-defined. (4) A strict reward and punishment system should be established to ensure that all workers perform their tasks responsibly. By taking these measures, the quality of inspection can be improved, with clearer standards, thereby facilitating subsequent works [6].

4.2. Strengthening of material testing

For bridge projects in highway reconstruction and expansion projects, ensuring the quality of the materials is

the key to ensuring the overall quality of the project. Therefore, the materials used in these types of projects should be inspected thoroughly. Currently, the main materials used in such projects include cement, sand, gravel, steel bars, etc. Several strategies can be adopted in the inspection of materials. (1) The materials should be inspected at the production site before they are transferred to the construction site. The materials should only be transferred after confirming that they are up to standard. (2) Another round of inspection should be done when the materials arrive at the construction site [7]. Unqualified materials should be returned to the manufacturer promptly. (3) The materials should be inspected for the last time before being put into use [8]. In this way, the quality of all materials in the construction of such projects can be well guaranteed. By taking these measures, defects caused by subpar materials can be avoided.

4.3. Improvement of comprehensive quality of inspection personnel

The competence of the staff will directly impact the inspection quality. Therefore, the comprehensive quality of inspection personnel should be cultivated [9]. The quality of the staff can be improved through several ways. (1) The recruitment standards for inspection technicians should be raised, and staff with a university degree in related fields and experienced staff should be prioritized. (2) All staff members should be given regular training to ensure that they are updated about the latest technologies and equipment available [10]. (3) All staff members should be assessed regularly and their wages should be proportionate to their competence. These measures can help improve the quality of inspection by reducing human factors.

5. Conclusion

As the number and scale of modern expressway reconstruction and expansion projects continue to increase, bridge engineering inspection has also been increasingly highlighted by relevant experts. Proper structural inspection should be carried out to effectively ensure the quality of bridge structures in such projects. Besides, it is important to improve the quality of inspection to facilitate the development of modern highway reconstruction and expansion bridge projects.

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The authors declare no conflict of interest.

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Patterns of Interactions of the Complex City System: Emotional Urban Objects as Triggering Agents – A Secondary Publication

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Abstract: This article presents an analysis of the patterns of interactions resulting from the positive and negative emotional events that occur in cities, considering them as complex systems. It explores, from the imaginaries, how certain urban objects can act as emotional agents and how these events affect the urban system as a whole. An adaptive complex systems perspective is used to analyze these patterns. The results show patterns in the processes and dynamics that occur in cities based on the objects that affect the emotions of the people who live there. These patterns depend on the characteristics of the emotional charge of urban objects, but they can be generalized in the following process: (1) immediate reaction by some individuals; (2) emotions are generated at the individual level which begins to generalize, permuting to a collective emotion; (3) a process of reflection is detonated in some individuals from the reading of collective emotions; (4) integration/significance in the community both at the individual and collective level, on the concepts, roles and/or functions that give rise to the process in the system. Therefore, it is clear that emotions play a significant role in the development of cities and these aspects should be considered in the design strategies of all kinds of projects for the city. Future extensions of this work could include a deeper analysis of specific emotional events in urban environments, as well as possible implications for urban policy and decision making.

Keywords: Emotional events; Urban objects; Complex adaptive systems; Adaptive complex systems; City

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1. Introduction

Cities can be described as dynamic systems made up of multiple agents and entities of different natures that constantly interact with each other, originating phenomena such as identities, imaginaries, or behaviors at global and collective scales. These notions underpin the approach of cities as complex systems [1-3], that is, dynamic systems that behave in a nonlinear way, where small perturbations can have large effects on the structure and function of the city. This approach is useful because it establishes that interactions, initial conditions, and time are variables that influence and explain the processes that give rise to various observable phenomena in cities, such as the emergence of behavioral patterns, the growth of urban areas, public health problems, and traffic flow.

In an urban adaptive complex system, urban objects can be conceptualized as physical or non-physical elements that are part of the system and interact with other components of the system to influence its behavior and adaptation [3,4]. They have a systemic function, either individually or as a conceptual whole (for example, cars in the city). Urban objects can include buildings, streets, squares, parks, transportation systems, communication networks, information systems, and digital services among others [4,5]. Therefore, the concept of an object is not only limited to the physical but also carries over to the intangible.

Urban objects can influence the emotions and behaviors of the people who interact with them. For example, a well-designed public transport app can facilitate mobility and reduce stress for people using the system, while an inaccurate or confusing information system can generate confusion and frustration in users [4]. The emotions of individuals interacting with urban objects can affect their behavior and decision-making within the system. If a person feels comfortable and safe in a public space, they are more likely to spend time there and interact with other users of the space [6]. Therefore, emotional urban objects can be defined as observable entities in the urban environment that generate a significant emotional response in the people who perceive or interact with them. Emotional urban objects can involve in their nature material, immaterial elements, eventualities, activities, and/or actions.

The importance of the topic lies in the fact that, at present, there is a growing concern among architects, urban planners, and designers about the role of social emotions in the configuration of urban environments [7]. Social emotions refer to feelings and attitudes that arise from social interactions, such as empathy, trust, and a sense of belonging [8]. When speaking of social emotions, we can identify them with collective emotions, as the concept points to an emotional state shared by a multiplicity of individuals in response to a common event, situation, or stimulus. Although urban planning and design often focus on functionality and efficiency, it is important to consider the impact of these factors on the social well-being and emotional experiences of city dwellers. Understanding the interconnections between urban objects and emotions can be important for designing more adaptive and sustainable urban systems [4].

The problem posed is that the omission of social emotions in urban planning and design can lead to a lack of social cohesion, a sense of isolation, and a reduced quality of life for city residents [9]. The central question of this article is as follows: “Are there patterns of coincidence in different emotionally charged objects or events within the urban system?” The purpose of this article is to explore the importance of emotions in the complex urban adaptive system by analyzing patterns in emotionally charged events, both positive and negative. In addition, recommendations for future research and practice in this area will be proposed.

2. Methods

In this study, qualitative research was performed based on observation and case analysis of urban emotional objects. The selection of the cases was done in a non-probabilistic way, using a purposive sampling of objects and events of high emotional charge in different cities.

The study population was the communities related to a sample of urban objects and 7 events of high emotional charge in different cities of the world, selected through purposive sampling. Cases were chosen on the basis of representing a diversity of urban and cultural contexts. The cases were selected based on the available information and accessibility to the places where the objects or events were located.

The study was carried out in different cities on different continents. The selected locations included public spaces, emblematic buildings, social and cultural events, and transportation systems. The locations were selected based on the presence of emotionally charged objects or events and their cultural or social relevance. These events included situations of social participation, art, symbolic objects, political situations, and even religious beliefs.

Table 1. List of selected cases of emotional urban objects for the analysis of the study

Emotional urban object	Location	Type of object	Meaning/background
Auschwitz Museum	Krakow, Poland	Historical	A memorial to the Holocaust victims during World War II.
Feminist protests at the Angel of Independence monument	Mexico City, Mexico	Historical	A commemoration of the beginning of the struggle for Mexico's independence in 1810.
Construction of the Macroplaza	Monterrey, Nuevo Leon, Mexico	Public plaza	A center for cultural and recreational activities in the city center of Monterrey, Nuevo León, Mexico.
Christ the Redeemer statue	Rio de Janeiro, Brazil	Religious Monument	It represents the faith and devotion towards the Catholic religion.
Fall of the Berlin Wall	Berlin, Germany	Historic	A symbol of the Cold War and the division between East and West Berlin.
The revolutionary painting *of Emiliano Zapata in Heels*	Mexico City, Mexico	Plastic art	Social criticism on the iconic character of the Mexican Revolution and gender roles.
Loma Larga Mural	San Pedro Garza Garcia, Nuevo Leon, Mexico	Urban art	It expresses the cultural identity and local history of the community.

Data was collected through observation and analysis of secondary sources, such as media and social media posts. The data recorded included the characteristics of the objects or events, their design, the social imaginaries surrounding them, functionality, interaction with the environment, and the emotional response of the people who interacted with them. Qualitative analytical tools were used to classify the data and establish patterns of coincidence in the different objects and events with high emotional charge. The emotional events were analyzed through focus groups, made up of citizens residing in northeastern Mexico, between 18 and 22 years of age, who were trained in emotional design studies. Each emotional event was analyzed in four steps. The steps followed in the analysis of each emotional event are as follows: (1) The origin of the emotional event was discussed and analyzed, identifying what triggered the emotions in people and how this affected their perception of the situation. (2) The actors involved in the event were identified, including both individuals and moral entities, and the role they played in the situation was analyzed. The ways in which an emotional event permeated other interactions and contexts were explored, generating new emotional responses and actions by the actors involved. (6) The timing and reasons for the dilution or alteration of the emotional event were determined, and the duration and evolution of the event and how this was reflected in the actors' responses and the environment were also analyzed. Qualitative content analysis was used to examine the data collected and establish emerging patterns and categories. Thematic and open-coding analyses were conducted to identify patterns and themes in the data collected.

3. Results

The results of the research indicate that emotional events can be triggered by different factors, such as visiting a historically significant place or analyzing a work of art that leaves an emotional impact on the viewer. The actors involved in these events may include both individuals and moral entities, such as institutions or social movements.

It was found that emotional events can have a significant impact on the perception and behavior of the actors involved at the individual level. Moreover, these events can extend beyond the time and place in which they occurred, transforming into collective emotions. For example, the emotion generated by a visit to a historical site can influence the way visitors interact with the world and can lead to new emotional responses and actions by the actors involved. From this, the observable factors of emotional urban objects were categorized,

i.e. the elements involved in the phenomenon: triggering event (emotional event, intervening actors, processes [consequent dynamic actions], interactions and emergent phenomena, and finally the adaptive logic of emotions [the transformation or non-transformation of meanings], or the dilution/duration of the emotional event).

The following is a summary of the analysis of each emotional object, which describes the factors according to the nature, condition, and information they generate (**Tables 1–8**).

3.1. Auschwitz Museum, Krakow, Poland

The origin of the emotional event at the Auschwitz Museum was the publication of images of visitors performing actions that were disrespectful toward the Holocaust victims. Social media also played an important role in spreading the emotional event.

The actors involved in the event were the visitors of the Auschwitz Museum and society in general, who expressed their opinions and feelings towards the event. The visitors in this case offended the victims of the Holocaust and the museum, while the society expressed its indignation and support for the museum.

The emotional event sparked a huge controversy, which led to a wider dissemination of the story behind the museum and an increase in the number of visits to the site. In addition, the event led to new emotional responses and actions by the actors, as the museum took steps to prevent the recurrence of such actions.

The impact of the emotional event diluted over time and with the action taken by the museum to avoid this type of event from happening again. Despite that, the museum will continue to be a place that will resonate with people due to its historical significance.

The origin of the emotional event was found to be related to the presence of stimuli that are historically or culturally significant. These stimuli can be places, objects, or symbols, among others. The analysis of the role of the actors involved in the emotional event allowed us to identify that the perception and reaction of individuals are influenced by their cultural background, previous experiences, and belief systems.

Table 2. Observable factors of the urban emotional object: Auschwitz Museum, Krakow, Poland

	Factors
Emotional event	Posting selfies and frivolous actions at the Auschwitz Museum.
Actors	Museum visitors, society
Processes	Using social media and visiting the museum
Interactions triggered	Opinions and feelings of the society, debates on social media, visits to the museum
Emerging phenomena	Increase in museum visits, change in visitors' attitudes
Adaptive logic of emotions	Emotions will always be triggered when visiting a place with a painful and significant history like the Auschwitz Museum.

3.2. Feminist protests at the Angel of Independence monument, Mexico City, Mexico

The actors involved were women who came together to fight against gender violence and the collectives that have supported them. In this case, the report of alleged rape by Mexico City police officers and the lack of action by the Secretariat of Citizen Security (SSC) served as a trigger for the emotional event.

The processes that took place included the protest at the Independence Monument, the graffiti on the monument, and the subsequent marches. Women played the leading role in the protest and in spreading awareness of gender violence and the need for radical measures.

The interactions and emerging phenomena of this case include a greater number of women joining the movement each year, the increasing attention of the authorities on the parades, and the police groups that have

stormed the demonstrations. In addition, the emotional event has led to greater public awareness of gender-based violence and has encouraged many women to fight for their rights.

This emotional event has not been diluted over the years, and the fight against gender violence persists, with the Independence Monument retaining its symbolic significance as a site for advocating against this issue. In this case, women have decided to continue fighting until they are heard and there is a change in the country.

Table 3. Observable factors of the urban emotional object: Feminist protests at the Angel of Independence monument, Mexico City, Mexico

	Factors
Actors	Women and groups fighting against gender-based violence.
Role of the actors	Protest at the Independence Monument, graffiti on the monument, and parades.
Interactions triggered	Increase in women joining each year, accompanied by increased attention from authorities during the marches, and instances of police groups forcibly entering demonstrations.
Emerging phenomena	Increased public awareness of gender violence and women's rights.
Duration of the emotional event	The event has not fizzled out and the fight against gender-based violence goes on.

3.3. Construction of the Macroplaza, Monterrey, N.L., Mexico

This is an example of analysis where the actors involved are the government headed by the governor, those affected (homeowners and business owners), and public opinion. The emotional trigger was the demolition of historic buildings and homes for the construction of the Macroplaza.

The processes that took place included the construction of the Macroplaza, the protest of those affected and the general public, and the constant adaptation of citizens to the new reality. The interactions and emergent phenomena of this SCA include the creation of a culture and heritage in Nuevo León through important events in the city and monuments, fountains, and green areas that have helped to recover and compensate for the territory and the environmental and socioeconomic impact of its decade. The adaptive logic of emotions in this case was the constant adaptation of citizens to the new reality, accepting the progress and growth of the state through works such as the Macroplaza while preserving the culture and heritage of the region. The emotional event was diluted through this constant adaptation and the acceptance of the citizens.

Table 4. Observable factors of the urban emotional object: Construction of the Macroplaza, Monterrey, N.L., Mexico

	Factors
Origin of the emotional event	Demolition of historic buildings and homes for the construction of the Macroplaza.
Actors	The government, the affected parties (homeowners and business owners), and public opinion.
Role of the actors	The construction of the Macroplaza, protest by those affected and the general public, and constant adaptation of citizens to the new reality.
Interactions triggered	There were arguments between those who supported the construction of the statue and those who opposed it.
Emerging phenomena	The creation of a culture and heritage in Nuevo León through significant events in the city, monuments, fountains, and green areas have helped recover and offset the territory and the environmental and socio-economic impact of its decade.
Adaptive logic of emotions	Constant adaptation of citizens to the new reality, accepting the progress and growth of the state through works such as the macroplaza, while preserving the culture and heritage of the region.
Dilution of the emotional event	The event was diluted through the constant adaptation of the citizens to the new reality and the acceptance of the progress and growth of the state through works such as the Macroplaza. There is no exact date since it was a matter of constant adaptation of the citizens of the region.

3.4. Construction of a religious statue (Christ the Redeemer), Rio de Janeiro, Brazil.

This example of analysis where the emotional trigger was the construction of a religious statue, which caused controversy and protests in the communities of the region. The actors involved were the communities of the region and the committee for the construction of the statue. The protests and controversies permeated at the legal and social levels.

The processes that took place included the construction of the statue, the protests of the communities, the legal defense by the Attorney General of the Republic, and the adaptation of the committee for the construction of the statue to the criticism received. The interactions and emergent phenomena of this SCA include the legal defense and social criticism surrounding the statue, and its subsequent acceptance once completed. The adaptive logic of emotions in this case was the adaptation of the committee for the construction of the statue to the criticism received, which led to changes in the design of the statue. The emotional event was diluted once the communities in the region saw the beauty of the end product and the message it conveyed.

Table 5. Observable factors of the urban emotional object: Construction of a religious statue (Christ the Redeemer), Rio de Janeiro, Brazil

	Factors
Origin of the emotional event	The construction of a religious statue (Christ the Redeemer) in the region caused controversy and protests.
Actors	The communities of the region were the main actors and opposed the construction of the statue.
Role of the actors	There was controversy over the construction of the statue, including its legality and the form it would take.
Interactions triggered	There were arguments between those who supported the construction of the statue and those who opposed it.
Emerging phenomena	The construction of the statue had a significant religious and cultural message, so it was eventually accepted.
Adaptive logic of emotions	The stakeholders adapted to the situation and accepted the statue once it was built.
Dilution of the emotional event	The emotional event faded when the community saw the beauty and significance of the end product.

3.5. Fall of the Berlin Wall, Germany

The example of the fall of the Berlin Wall can be taken into account in this analysis because it involves multiple interrelated actors, processes, and emerging phenomena. The main actors in this event include German citizens, the East German government, the West German government, and international governments. Processes that contributed to the fall of the wall include popular pressure, the political opening of the East German government, the elimination of political repression by the Soviet Union, free elections in Poland, and the opening of borders in Hungary.

The interactions that resulted from the fall of the wall were extensive and varied, including the unification of the Germanys and the dissolution of the Soviet Union, which ushered in a new world order. In addition, the event also permeated popular culture, international politics, and socio-spatial dynamics in Germany, as there are still noticeable differences in the German territory. As for the dilution of the emotional event, it is difficult to establish a specific time, as the fall of the wall had a lasting impact on global history and culture. However, it can be said that the initial shock of impact from the fall of the wall gradually diminished as people began to face the challenges of the reunification of the two Germanys and the socio-economic differences that persisted.

Table 6. Observable factors of the urban emotional object: Fall of the Berlin Wall, Germany

	Factors
Origin of the emotional event	The fall of the Berlin Wall and the series of political events that preceded it.
Actors	German citizens, the East German government, the West German government, and international governments.
Role of the actors	Governments made political decisions, while citizens protested and demanded their rights.
Interactions triggered	The unification of the two Germanys, the end of the Cold War, and the fall of socialism in Eastern Europe.
Emerging phenomena	A new world order, the dissolution of the Soviet Union, the preservation of parts of the wall as a historical symbol, and the persistence of the socio-spatial division in Germany.
Adaptive logic of emotions	The event unfolded over several decades, but the fall of the wall itself occurred in November 1989.
Dilution of the emotional event	The event has lost some of its emotional impact over time, but it remains a significant historical milestone in modern German and world history.

3.6. The revolutionary painting *Emiliano Zapata in Heels*

The event analyzed involves different actors, such as the museum, the LGBTQ+ community, the descendants of Emiliano Zapata, the president of Mexico, the author of the painting, and Mexican society. The exhibition of the painting generated an emotional reaction in Mexican society due to the distortion of the image of a national hero and the prejudice towards the LGBTQ+ community. The interactions between the actors were diverse and complex, including protests and artistic manifestations on social media. This event resulted in the questioning of toxic masculinity and the reconsideration of history and its heroes, in addition to the growth in popularity of the artist. The emotional event lasted approximately two weeks and its relevance diminished over time, but the reflections and questions generated continue to be present in Mexican society.

Table 7. Observable factors of the urban emotional object: Painting "The Revolution" by Emiliano Zapata with heels

	Factors
Origin of the emotional event	Exhibition of a painting depicting Emiliano Zapata with female features.
Actors	The museum, the LGBTQ+ community, the descendants and followers of Emiliano Zapata's ideals, the Mexican president, Fabián Cháirez (the author), social media, and Mexican society.
Role of the actors	Each actor reacted emotionally to the exhibition of the painting, generating diverse responses and protests
Interactions triggered	Protests at the museum by peasant groups and Zapata's relatives, protests in favor of the work by the LGBTQ+ community, press and social media coverage, artistic demonstrations, and social media tributes for and against the painting.
Emerging phenomena	Questioning of the concept of "macho" and toxic masculinity in Mexican society, reconsideration of history and its heroes, increase in popularity and recognition of the artist Fabián Cháirez.
Adaptive logic of emotions	Approximately two weeks.
Dilution of the emotional event.	The relevance of the theme gradually diminished until it was diluted over time, although the reflections and questions generated by the exhibition of the painting are still present in Mexican society.

3.7. Loma Larga Mural, Monterrey, N.L., Mexico

This example of analysis involves multiple actors and processes that interact with each other, generating emergent phenomena. The main actors in this system were the neighbors of the area, the painter, the mayor, and society in general. Each of them played a role in the dynamics of the system, contributing different perspectives and opinions that influenced the way the emotional event was perceived.

The processes involved include the creation of the mural, society's reaction to it, decision-making by the authorities, and society's response to those decisions. These processes are interrelated and affect the final outcome of the system. The interactions between actors and processes generated controversy surrounding the mural, the creation of alternative proposals, and the persistence of the issue in society over time.

Regarding the adaptive logic of emotions, these are a natural response of the organism to situations perceived as threatening or stressful. In this case, the negative emotions that arise when viewing the mural are a form of adaptation to an environment that is perceived as dangerous or threatening. Through emotional reaction, people stay alert and avoid situations that may put their safety at risk. In this sense, emotions are an adaptive tool that helps the organism to face and adapt to its environment.

Table 8. Observable factors of the urban emotional object: Loma Larga Mural, Monterrey, N.L. Mexico

	Factors
Origin of the emotional event	The use of explicit symbols and somber techniques in a city mural.
Actors	The neighbors, the painter, and the mayor of San Pedro.
Role of the actors	The neighbors generated disgust and fear, while the painter and mayor were criticized for the choice of the mural.
Interactions triggered	Conversations and debates on social media platforms, proposals for new designs for the mural, and critical analyses of the work.
Emerging phenomena	Fear and stress among people living near the mural, controversy, and debate among the public.
Adaptive logic of emotions	The controversy started in September 2017 and continues to be a topic of conversation in society.
Dilution of the emotional event	The mural remained in place despite criticism, but different proposals were allowed to be used on it.

4. Conclusion

After analyzing the examples presented in this article, we can conclude that there are patterns of coincidence in emotionally charged objects or events within the urban system. It is important to highlight that the emotional event can influence the emergence of other phenomena and generate new emotional responses different from those that gave rise to it. For example, the creation of new communities, as in the case of the Loma Larga Mural, or the feeling of guilt, as in the case of the Auschwitz Museum. This is explained by the complexity of the emotional experience, which involves multiple factors and is not limited to a single situation or context. Moreover, the duration and evolution of the emotional event may vary depending on internal and external factors, such as the presence or absence of certain stimuli, the social and cultural context, as well as the individual's capacity to process and regulate his or her emotions. In addition, it was found that the reactions of the actors during the emotional event can lead to the formation of groups that last beyond the duration of the event and act as initiators of new communities or groups where other interests are pursued, maintaining contact. On the other hand, emotional events that have a media impact or greater reach tend to destabilize system beliefs

and challenge the status quo, giving rise to new dynamics. Understanding the emotional phenomenon is of great importance to understand how it influences the perception and behavior of individuals in various situations in the urban environment. This can have relevant implications in different fields, from psychology to anthropology and sociology, as well as in decision-making and public policy.

In short, the patterns depend on the characteristics of the emotional charge of the urban objects, but the patterns of interaction in which they coincide can be generalized as follows in the complex city system: (1) immediate reaction by some individuals; (2) emotions are generated at the individual level which begins to generalize permuting to a collective emotion; (3) a process of reflection is detonated in some individuals from the reading of collective emotions; (4) integration/meaning in the community both at the individual and collective level, on the concepts, roles and/or functions that give rise to the process in the system.

These findings contribute to the knowledge about the relationship between emotional events and their influence on the urban system. Therefore, future research should delve deeper into the emotional dynamics of the groups generated during and after these events, as well as the role of the media in the destabilization or consolidation of a system and its influence on decision-making and public policies.

Disclosure statement

The authors declare no conflict of interest.

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Automatic Sensing and Detection for Subway Tunnel Pathologies

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Abstract: Subway tunnels often suffer from surface pathologies such as cracks, corrosion, fractures, peeling, water and sand infiltration, and sudden hazards caused by foreign object intrusions. Installing a mobile visual pathology sensing system at the front end of operating trains is a critical measure to ensure subway safety. Taking leakage as the typical pathology, a tunnel pathology automatic visual detection method based on Deeplabv3+ (ASTPDS) was proposed to achieve automatic and high-precision detection and pixel-level morphology extraction of pathologies. Compared with similar methods, this approach showed significant advantages and achieved a detection accuracy of 93.12%, surpassing FCN and U-Net. Moreover, it also exceeded the recall rates for detecting leaks of FCN and U-Net by 8.33% and 8.19%, respectively.

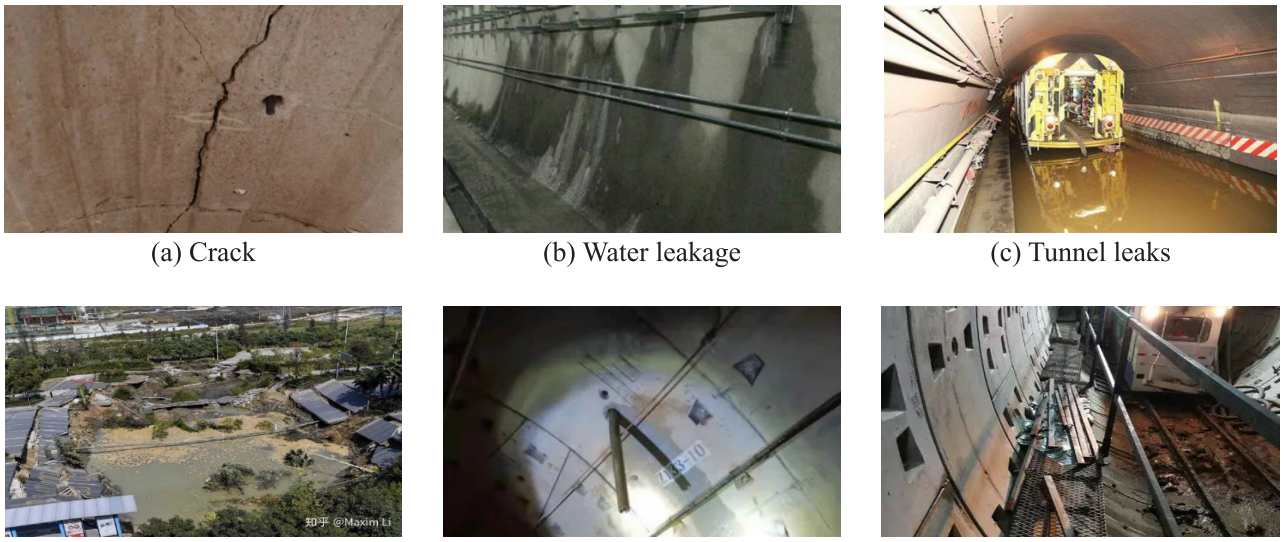
Keywords: Visual detection; Neural network; Health monitoring; Image segmentation; Water leakage; Subway tunnel.

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1. Introduction

There are several types of tunnel defects, including segment leakage, cracks, lining misalignment, track bed hollowing, concrete deterioration, and cross-section ovalization. In addition, intrusion boundary phenomena caused by construction, support structure deformation, surrounding rock deformation, etc. also occur from time to time. At the same time, sudden hazards such as track damage and falling interference objects may also occur (**Figure 1**). If these defects are not dealt with in time, they will have a serious impact on society and the economy [1]. Among them, water leakage is one of the most common defects in subway lines [2]. The running interval of subway trains is very short. The average interval of the Beijing subway is 3–5 minutes, and it may even be shortened to 2 minutes during peak hours. Therefore, timely and fast on-board inspection of tunnels is particularly important.

The fully automatic tunnel defect sensing system enables automatic sensing of subway tunnel defects. The system consists of two subsystems, namely the mobile visual defect sensing system and the processing feedback system (**Figure 2**).



(a) Crack (b) Water leakage (c) Tunnel leaks

(d) Water leakage causing collapse (e) Drill bit penetrating the tunnel (f) Silt and debris

Figure 1. Common defects of subway tunnel

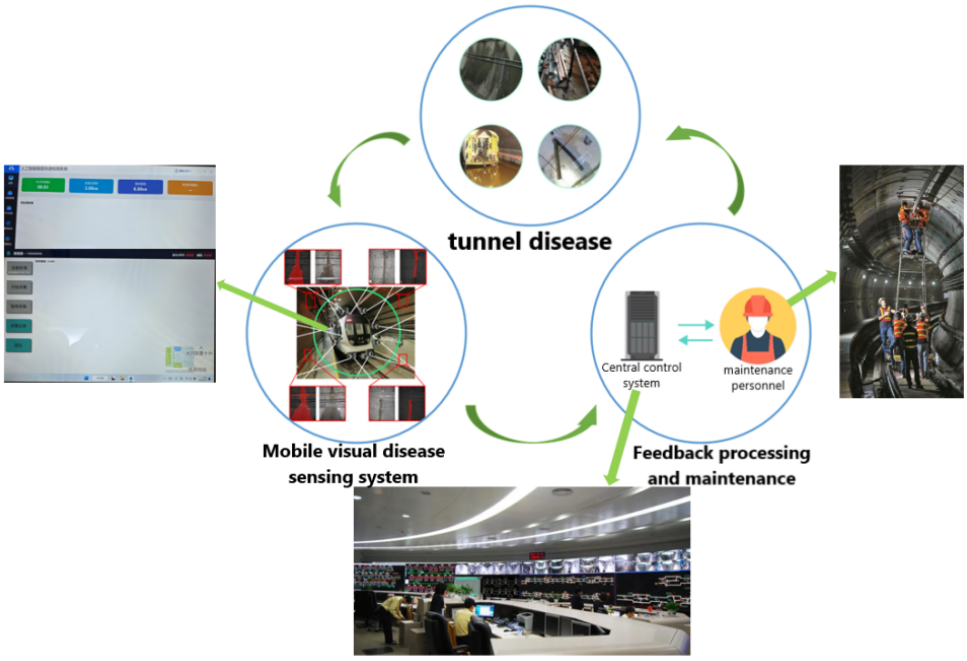


Figure 2. Fully automatic tunnel disease visual perception system

In the mobile visual disease sensing system, 8 high-resolution industrial charge-coupled device (CCD) cameras are installed on the top, left and right sides, and bottom of the subway train, and the sensing system is composed of LED lighting equipment, power supplies, and lifting platforms. By taking a circular shot of the tunnel, image data of the entire tunnel is obtained [3]. The image processing technology is used to analyze and detect images to detect various diseases in subway tunnels promptly [4]. Then, multiple positioning methods are integrated to obtain disease location information in real time. The mobile defect sensing system is connected to the train operation central control system, so the location of the defect can be detected based on the train mileage and the defects detected. Second, the inertial navigation recorder is used to record the train acceleration and angular velocity, and the position of the defect will be calculated based on these two information. By

integrating the information obtained by the two aforementioned calculations, the precise location of the defect in the tunnel can be obtained and sent to the processing feedback system.

In the processing feedback system, the central control system generates and distributes maintenance tasks based on the information provided by the mobile visual defect sensing system. Maintenance personnel can then be allocated to repair the subway tunnel defects based on the type and location of the defect to ensure operational security and stability. In this process, it is important to accurately categorize the type of disease to facilitate repair work.

In recent years, the advancement of computer technology has brought rapid development to visual measurement. Machine learning methods can be used to segment the area of water leakage more accurately. Xue *et al.* [5] adopted fully convolutional (FCN) and Dai *et al.* [6] local-based FCN (R-FCN) to label, classify and detect cracks and leaking water. Huang *et al.* [7] used FCN to perform semantic segmentation of leaking water. However, small leaks may be overlooked due to their spatial invariance characteristics [8]. Hu *et al.* [9] improved the MSRCR algorithm to enhance crack images and combined the crack coordinate design algorithm and the SVM support vector machine method to classify crack types. Tian *et al.* [10] used the target detection algorithm MaskR-CNN to automatically detect water leakage in two-dimensional images, thereby producing a high-quality segmentation module. Jiang *et al.* [11] proposed a subway tunnel crack target detection scheme based on deep learning, using a deep convolutional generative adversarial network to achieve sample expansion, and using YOLOv5 and digital image processing technology to achieve intelligent identification of subway tunnel cracks. However, the network structure does not take into account computational efficiency. Orimasa *et al.* [12] used the improved SSD fully convolutional network structure to complete the intelligent identification and category labeling of targets such as cracks. Zhao *et al.* [13] proposed using the MaskR-CNN network for water leakage detection and verified that this model can achieve precise positioning and pixel segmentation of water leakage. Zhu *et al.* [14] proposed an improved YOLOv5 target detection model. According to the position and scale characteristics of the target, the original model was optimized around the detection accuracy, model parameters, and detection speed. However, due to the complexity of the environment, the detection accuracy is still not guaranteed.

There is still room for optimization in the automatic detection of subway tunnel defects in terms of coping with complex environmental challenges and detection accuracy. We proposed a fully automatic tunnel disease perception system composed of a mobile visual disease perception system and a processing feedback system called Automated Subway Tunnel Pathology Detection System (ASTPDS). This system was created based on Deeplabv3+, which is used for the semantic segmentation of tunnel diseases. The adoption of StepLR and CosLR learning rate decay algorithms makes the model more stable, converges faster, and has better generalization performance. The Adam optimizer was used to improve model training speed, performance, and generalization capabilities. The focal loss function was used to overcome positive and negative sample imbalance. This system could accurately segment leaking water areas in various complex environments and had excellent segmentation accuracy.

2. Automatic segmentation method of tunnel diseases

ASTPDS consists of two modules, in which the encoding area is used to extract high-level semantic information; and the decoding area is used to extract low-level semantic information, as shown in **Figure 3**.

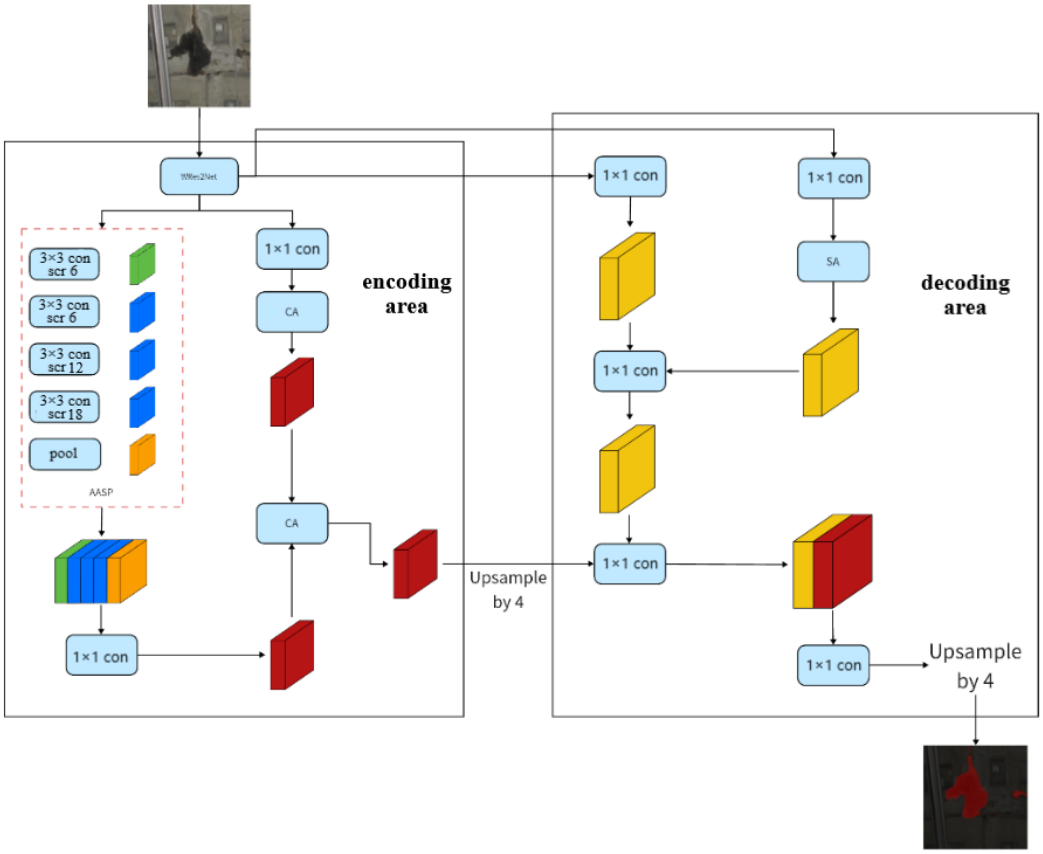


Figure 3. ASTPDS network structure diagram

The backbone network of ASTPDS consists of the WRes2Net network, which is used to extract leakage water feature information. The channel attention mechanism (CA) is used in the coding area to extract the depth of the channel to separate the convolutional layer features and achieve accurate allocation of high-response channels. Assuming that the high-level semantic information is $\psi_c^h \in I^{w \times h \times c}$, $\psi_c^h=[\psi_1,\psi_2 \ldots,\psi_c]$, among them, are the width and height of the input feature image respectively, and is the number of channels.

$$f_{CA}(g_c,\Phi_c)=s_1\{f_{c2}\{r[f_{c1}(g_c,\Phi_{c1})],\Phi_{c2}\} \quad (1)$$

In Formula (1), g_c is the feature map after ψ_c^h average pooling, Φ_c is the parameter in the channel attention module, s_1 is the sigmoid activation function, f_C represents the fully connected layer, and r is the ReLU activation function. The CA module outputs f_{CA} and weights the ASSP feature map to obtain the output feature map $\psi_c^{h'}$, as shown in Formula (2).

$$\psi_c^{h'}=\psi_c^h \cdot f_{CA} \quad (2)$$

Compared with the encoding area, the decoding area can obtain features such as the location and edge of the target information, but there is a large amount of background information, which will affect the accuracy of segmentation to a certain extent. The spatial attention mechanism (SA) is used in the decoding area to focus on the target feature area, adaptively combine high-level features with low-level features, and use high-level features to filter out background information. In this way, global information can be obtained without increasing the parameters and semantic segmentation can be improved through global convolutional networks. Besides, a two-layer convolution operation is used. The two-layer convolution kernels are $1 \times k$ and $k \times 1$ respectively, which are used to obtain key feature information.

$$A_1 = Conv_1[Conv_2(\psi_c^h,\Phi_{s1}),\Phi_{s2}] \quad (3)$$

$$A_2 = Conv_2[Conv_1(\psi_c^h, \Phi_{s1}), \Phi_{s2}] \quad (4)$$

$$f_{CA}(\psi_c^{h'}, \Phi_{s1}) = S_2(A_1 + A_2) \quad (5)$$

In Formulas (3)–(5), A_1 is the feature map completed by convolution of convolution kernels 1 × 5 and 5 × 1, A_2 is the feature map completed by the convolution of convolution kernels 5 × 1 and 1 × 5, $Conv_1$ is 5×1×C convolution kernel, $Conv_2$ is the convolution kernel of 1 × 5 × C, S_2 is sigmoid activation, and $\psi_c^{h'}$ is obtained by SA weighting.

Training complex deep learning models may take a long time. Adding learning rate decay methods and optimizers can increase the training efficiency of the model and achieve better training results. The learning rate decay method STEPLR is used during the training process to effectively improve the model convergence speed, prevent over-fitting, and improve model performance.

$$P = L_0 \times g^{f\frac{e}{s}} \quad (6)$$

In Formula (6), P represents the current learning rate, L_0 is the initial learning rate, g is the attenuation coefficient, e represents the current number of training rounds, and s is the size of the attenuation step. After each s training rround the learning rate will attenuate according to the attenuation coefficient g. The learning rate decay method CosLR is used to improve the convergence speed and generalization ability of the model.

$$P = 0.5 \times L_0 \times \left(1 + cos\left(\frac{e}{T}\right)\right) \quad (7)$$

In Formula (7), P represents the current learning rate, L_0 is the initial learning rate, e represents the current number of training rounds, and T is the total number of rounds of learning rate decay. At the same time, the optimizer SGD is used to update the model parameters to minimize the loss function and improve the accuracy and generalization ability of the model (Formula [8]).

$$w = w - l \times g \quad (8)$$

In Formula (8), w represents the weight parameter of the model, l represents the learning rate, and g represents the gradient of the loss function on the weight parameter. The optimizer Adam is used to adaptively update the model parameters to improve the convergence speed and generalization ability of the model.

$$m = b_1 \times m + (1 - b_1) \times g \quad (9)$$

$$v = b_2 \times v + (1 - b_2) \times g^2 \quad (10)$$

$$w = \frac{w - p \times m}{(sqrt(v) + ep)} \quad (11)$$

In Formulas (9)–(11), w represents the weight parameter of the model, p represents the learning rate, g represents the gradient of the loss function on the weight parameter, m and v are mean estimate and uncentered variance estimate, respectively. $sqrt(v)$ represents the square root of v, while ep is a constant used to stabilize the calculation and prevent division by zero.

After testing with the same optimizer, the network performance using CosLR is better. Under the same learning decay rate, the network performance of Adam is generally better than SGD.

$$Loss = \begin{cases} -\kappa\left(1 - y'\right)^{\delta}, y = 1 \\ -(1 - \kappa)y'^{\delta}\log\left(1 - y'\right), y = 0 \end{cases} \quad (12)$$

Additionally, training is divided into freezing and unfreezing phases. The focal loss function is used to

solve the imbalance problem of positive and negative samples, as shown in Formula (12).

3. Experiments and data analysis

3.1. Dataset construction

The experimental data set consisted of two parts. The first part was the lining water leakage data set of a subway tunnel in Shanghai, and the second part was the subway tunnel lining water leakage data set of a subway tunnel in Beijing collected by the mobile visual defect sensing system. The quality, shape, and dimensions of data were optimized for the training and application of deep learning models, thereby improving the accuracy and reliability of the model. The data were optimized through data source screening, data cleaning, data preprocessing, data partitioning, and data annotation.

Through data source screening and cleaning, abnormal and erroneous data were eliminated, and a total of 4,700 water leakage images were obtained. Data preprocessing included operations like statistical analysis of data, feature extraction, and normalization, in which the sizes of the images were standardized to 512 × 512 pixels. Next, the 4700-image data set was divided into a training data set and a test data set at a ratio of 4:1. Finally, manual annotation is used to mark the leakage area, which is regarded as the true value. The entire annotation task is completed using the LabelMe annotation tool.

3.2. Experimental program

Due to the complexity of the underground tunnel environment, water leakage exhibits characteristics such as irregular horizontal or vertical shapes, making it easy to go unnoticed, along with evidence of manual maintenance. This necessitates a network structure with excellent robustness to effectively address these challenges. Therefore, we divided the leakage data into five categories: blocky, vertical, horizontal, stain-covered, and occluded. FCN, U-Net, and ASTPDS were used for segmentation. The semantic segmentation effects were also compared to verify the advancement, accuracy, and robustness of ASTPDS.

$$P = \frac{TP}{TP+FP} \tag{13}$$

$$R = \frac{TP}{TP+FN} = \frac{(\mathrm{GT}-\mathrm{FN})}{\mathrm{GT}} \tag{14}$$

$$OAA = \frac{GT-FN+TN}{\mathrm{GT}+TN+FP} \tag{15}$$

$$DSC = \frac{2TP}{FP+TP+GT} \tag{16}$$

In Formulas (13)–(16), *TP* refers to the number of pixels of the leakage water image that is correctly segmented, *FP* refers to the number of pixels of the leakage water image that is incorrectly segmented, *FN* refers to the number of unidentified leakage water image pixels in the segmentation result, and *TN* refers to the unidentified leakage water image pixels in the segmentation result. Number of pixels leaking water, *GT* refers to the actual number of pixels leaking water.

Four key indicators, including precision (*P*), recall rate (*R*), overall detection accuracy (*OAA*), and model segmentation performance (*DSC*), were used to evaluate the network model's effectiveness in identifying water leakage. Precision measures the accuracy of positive predictions, while recall rate assesses the model's ability to detect real instances of leakage water. Overall detection accuracy offers a comprehensive assessment,

and model segmentation performance evaluates the accuracy of delineating leakage areas. Analyzing these indicators provides valuable insights into the model's performance in detecting water leakage.

3.3. Experimental results and discussion

In order to evaluate the performance of ASTPDS, a comparative test with similar models was designed. A total of FCN, U-Net, DeeplabV3+, and other models were selected and evaluated from five technical indicators. The calculation results are shown in **Table 1**.

Table 1. Performance comparison of different algorithms

Network type	Accuracy, *P* (%)	Recall, *R* (%)	*DSC* (%)	*OAA* (%)	Time (*h*)
FCN	87.24	87.15	87.25	99.423	23.51
U-Net	87.56	87.29	88.17	99.641	22.62
ASTPDS	93.12	95.48	94.02	99.941	21.25

All evaluation indicators of ASTPDS were better than other models, with detection accuracy increased by 5.88% and 5.56% respectively. The recall rate increased by 8.33% and 8.19%, respectively. The DSN representing the model segmentation performance increased by 6.77% and 5.85% respectively. The results showed that ASTPDS was superior to other models in all aspects, and its accuracy was significantly higher. As shown in **Figure 4**, ASTPDS performed significantly better than other similar models in terms of ModelLoss index. In addition, as shown in **Figure 5**, after the DSC coefficient stabilizes, its segmentation performance is also significantly better than that of similar models.

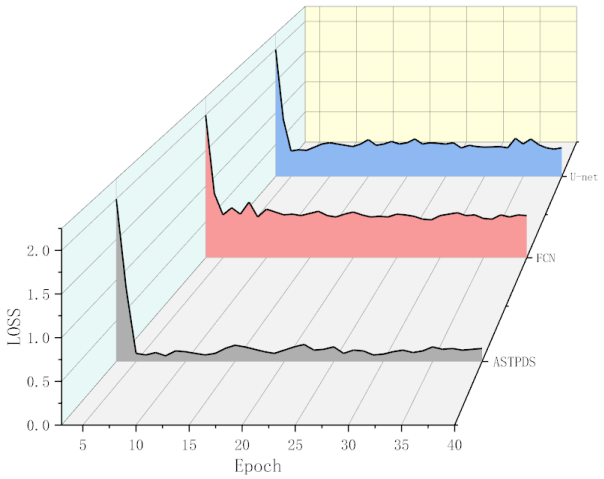


Figure 4. Model losses for different models

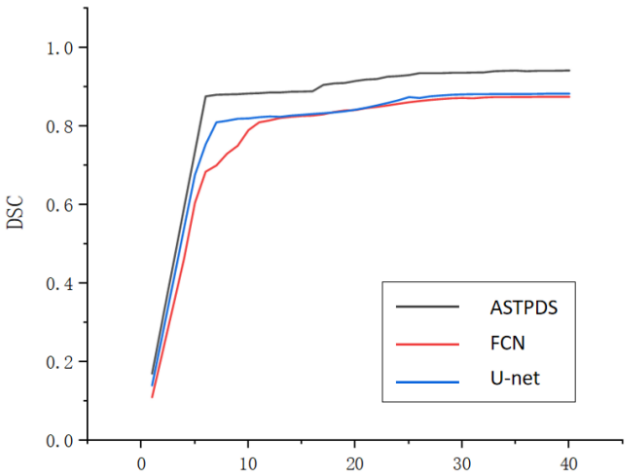


Figure 5. DSC comparison of different models

The categorization of water leakage by different systems is shown in **Table 2**. It can be seen from this that compared with block leakage water, U-Net has a better segmentation effect and can identify small leakage water blocks, while ASTPDS can segment small leakage more completely. For vertical water leakage, FCN segmentation is incomplete and U-Net suffers from overfitting. For horizontal strip water leakage, FCN has the problem of over-segmentation. For leaking water covered by stain, redundant background information appeared in the U-Net segmentation area, and the outline of the segmentation area was lacking or overfitting, while the segmentation by ASTPDS was finer and more complete. For occluded leakage, when the occluded part was

unknown, all three models showed good results, but FCN still had the problem of incomplete segmentation.

Table 2. Comparison of semantic segmentation methods for different types of leakage water

	Blocky	Vertical	Horizontal	Stain-covered	Occluded
Original image					
FCN					
U-Net					
ASTPDS					

4. Conclusion

Subway tunnels are often characterized by poor and uneven illumination, coupled with high levels of noise in images captured onboard trains. As a result, the accuracy of detecting leaking water, a common issue in subway tunnels, tends to be low. Addressing the challenges posed by this complex environment, this paper introduces a novel vehicle-mounted pixel-level visual sensing detection method. This method enables fully automatic and highly accurate identification and segmentation of tunnel leakage water.

Through extensive experimental testing, the proposed water leakage detection model (ASTPDS) showcased superior performance compared to other similar models. Specifically, the detection accuracy improved by 6.74%, the recall rate increased by 9.56%, and the segmentation performance saw a notable enhancement of 7.76%.

Disclosure statement

The authors declare no conflict of interest.

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Analysis of Citizen Participation in Urban Planning of Comala, Colima, Mexico – A Secondary Publication

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Abstract: The objective of this study was to determine the degree of citizen participation in urban planning processes in the municipality of Comala, Colima, Mexico to have a broader vision of the citizens and the environment in which they live. An instrument was designed specifically to perform this study and the instrument was validated by calculating Cronbach's Alpha. The results showed that citizens were highly involved in issues concerning their urban environment, and the main problems of the public spaces were also identified.

Keywords: Citizen participation; Planning; Urban development program

Online publication: February 26, 2024

1. Introduction

Planning cities without the citizens in mind will cause negative effects in terms of social, economic, and ecological aspects, which play an important role in the development of the city and implementation of the Municipal Urban Development Plans (MUDP). Integrating citizen participation in the study of urban sprawl can allow a better understanding of the social issues of a particular entity while addressing the needs of the surrounding environment. The participation of the population in urban planning is an act of democracy [1].

In the history of urban planning in Mexico, there has been a lack of governance on development plans. The creation of different programs that promote citizen participation arises from the interests of society in both private and public sectors, and vice versa [2].

The Secretariat of Agrarian, Territorial, and Urban Development (SEDATU) is a department established and included in the reform in 2013. It is prominently featured in the third paragraph of Article 27 of the Constitution, aiming to fully utilize the territory, and manage sustainability, urban settlements, and agrarian development. These actions are taken to ensure development and social peace [3].

Reducing multisectoral issues is one of the main objectives of the methodological guide issued by SEDATU, which provides tools for the development of a useful instrument for updating the MUDP. It allows the free selection of these tools by the internal authorities of each government headquarters [4].

Methodological guides and guidelines are documents issued by federal agencies that help establish the appropriate strategy for responsible entities to diagnose the needs of a specific urbanized area in order to address its weaknesses. The mentioned guidelines represent the simplified and most recent version recommended by SEDATU [5].

Countries such as Colombia and Chile have succeeded in developing methods of citizen participation like semi-structured interviews. These techniques promote simultaneous citizen planning initiatives and the development of appropriate urban planning for each locality [6].

Meanwhile, in Mexico, issues related to citizen participation have been overlooked in some localities. Problems regarding urban planning are often addressed through questionnaires and an understanding of the recreational activities of the locals. Integrating these tools with citizen participation could enhance strategies and the accuracy of information included in the MUDP [7].

Therefore, we created an instrument that can collect qualitative and quantitative information related to citizen participation. This instrument serves as a guide to improving strategies and the veracity of the information included in the MUDP. In the process of gathering and seeking information about citizen participation in urban development planning, it is important to understand the public's perception regarding aspects such as security, amenities, infrastructure, services, and accessibility. This allows for evaluating how citizens perceive these issues in comparison to the actual situation.

The creation of this tool is a collaborative effort by a team, and its development is a crucial step in crafting the MUDP for the municipality of Comala. This endeavor involves cooperation among working groups from the Honorable City Council of Comala, SEDATU, and the Postgraduate Division of the National Technological Institute of Mexico, Colima campus. The introduction of this instrument marks the first phase of an ongoing initiative to integrate citizen participation in decision-making processes within their community and, consequently, in urban planning [8].

In accordance with SEDATU guidelines and the estimated timelines set by the municipality for obtaining this information, it is proposed that the instrument be a survey administered to a sample of the communities with the highest population density in the municipality of Comala. The verification of the data obtained through the validation of the survey conducted in this article will be carried out in future lines of research.

The three centers of population with the highest demographic density were selected as the area of study. The center of population of Comala had a total of 1574 inhabitants, Cofradía de Suchitlán had 2021 inhabitants and, finally, Suchitlán had a total of 2714 inhabitants.

Comala is one of the ten municipalities of the state of Colima, Mexico. It is located in the north of the state, at coordinates 19° 18' and 19° 32' north latitude and between 103° 37' and 103° 57' west longitude [9]. The municipality of Comala is classified as one of the 132 Magical Towns of the Mexican Republic, as described by Mexico's Ministry of Tourism. Comala is made up of 118 communities [10].

Comala is a municipality with a rich cultural, architectural, and natural heritage, making the northern area of the municipality an excellent marketable product for real estate agents and, consequently, attracting buyers interested in exploiting the citizens' heritage irrationally. The disincorporation of these properties in the PMDU is a constant social issue faced by the authorities of the municipality, in addition to the social damages that this phenomenon triggers.

From a social point of view, urban planning with citizen participation should be carried out with a large

sample of the population. This is because by controlling this figure, it becomes possible to gauge the capacity of social groups from the various communities within the municipality of Comala to make decisions and commit to proper land use planning [1].

Disinformation and lack of citizen participation have been some of the main challenges in urban planning. To overcome this problem, it is important to establish a relationship between the citizens and their environment. In this way, different groups of people and their levels of vulnerability can be identified.



Figure 1. Location of the municipality of Comala, Colima, Mexico [10]

2. Methodology

The case study covers the social and legal issues that arise due to the lack of citizen participation in urban development planning. A structured methodology has been established for urban planning with citizen participation based on the public sector's (governmental) perspective as per the SEDATU guidelines. These guidelines include the selection of regulations and strategies for the inclusion of citizens in identifying deficient factors for proper urban planning [11].

While developing and reviewing documents related to citizen participation and tools for gathering information, we analyzed similar cases to tailor a tool that would assess the needs of individuals in the communities. This served as the basis for developing the MUDP for the magical town of Comala.

The needs of the population residing on the outskirts of the municipality across social, ecological, and economic domains were identified, in relation to the municipal center and its primary localities. Additionally, the official documentation recommended by SEDATU for the MUDP was analyzed. This aimed to select suitable indicators for the instrument that align with the specific needs of Comala municipality.

The MUDP was studied to understand the vulnerabilities of different groups of people so that urban problems could be identified through citizen participation.

The Mapping Cities Guide is the basis for the choice of the instrument, as it is a reference document suggested by SEDATU. This guide provides a broader perspective on the existing modalities of instrument

application for obtaining information. It outlines the methodology for developing a useful instrument and suggests the appropriate selection of tools for gathering information according to the needs of each city [12].

We referred to this document because it contains the survey instrument presented in this article. We found that the timelines for applying and developing the tool are appropriate for the municipality of Comala, from selecting the group of people to customizing the topics to be addressed, as well as considering the availability of the surveyed public.

For the selection of the sample in the urban setting, it was necessary to take into account the parameters established in the guide, which suggests that the surveyed groups comprise the immediate group in the study area, i.e., the centers of population in this case study: Comala, Cofradía, and Suchitlán [13].

The survey developed for the integration of citizen participation in the municipal development plan for Comala is based on the methodology suggested by SEDATU. Therefore, the details of the survey were structured based on the "Komunila Guide" [13].

A survey was considered an appropriate method of collecting information due to its quick and easy dissemination in the centers of the population. In addition, it can also be reused for studying other centers of population. It is inexpensive and can be done in different ways, which makes the collection of qualitative or quantitative information on a certain area easy. The results of this study can be analyzed and included in the urban planning of the municipality of Coma.

The survey was divided into three sections. The first section contained questions that were related to obtaining personal information about the respondent, which allowed us to understand the participants of the study area. The second section contained qualitative questions, which allowed us to learn about the perception of the participants towards the aesthetic qualities of their environment. Lastly, the quantitative section contained questions that helped identify citizen participation in the issues concerning the municipality of Comala.

The effectiveness and proper construction of the survey were evaluated prior to its implementation using Cronbach's Alpha, which allowed us to gain a more accurate insight into the effectiveness of the items in the survey. To fully understand Cronbach's Alpha formula, it is important to note that the coefficient provided by this tool is a statistical measure that quantifies the reliability or consistency of the items comprising a questionnaire. In other words, it assesses how well and to what extent the questions correlate with each other.

In this case, the items correspond to the variables listed in **Table 1**. The variable "K" represents the number of multiple-choice questions, excluding open-ended responses related to the respondent's knowledge. The sums were calculated using Equation (1) suggested by Cronbach's Alpha [14] and then the tabulated factors of the responses were added, replacing the values in the formula shown in Equation (1). It is worth noting that the minimum acceptable value obtained through this formula is 0.70, while the expected maximum value is 0.90. If parameters deviate from the mentioned ones, it could indicate inconsistency in the relationship between the items or redundancy and duplication in the counted items [15].

$$\alpha = \frac{K}{K-1}\left(\frac{\sum_{i=1}^{K} \sigma \frac{2}{Yi}}{\sigma^2 X}\right) \quad (1)$$

Besides, it is important to mention that, in addition to the validation through Cronbach's Alpha formula, the survey was applied as a pilot test to a representative sample of inhabitants of the municipality of Comala through Google Forms. The sample consisted of 36 participants, who responded from December 5, 2022, to March 26, 2023. Subsequently, the data were processed and calculated using the Cronbach's Alpha equation. The result of this test yielded a reliability of 75% in the execution and effectiveness of the survey, as shown in **Table 1** of the results section.

The format of the survey questionnaire is presented in **Appendix 1**. The first part of the survey consists of questions that are not quantifiable. Therefore, these items were not included in the total number of items applied in the Cronbach's alpha formula.

3. Results

The data from the aforementioned instrument yielded different results for each item. The overall result of this test showed a reliability of more than 75% in terms of execution and effectiveness of the survey, as shown in **Table 1**. Besides there was adequate consistency among the items of the questionnaire, making it suitable for field applications, since it is within the acceptable range according to Cronbach's Alpha formula.

Table 1. Cronbach's Alpha calculations

Variables	Value
Number of questions, *K*	22
Sum of individual variances, *Si*	20.7532224
Sum of total variances, *St*	73.11111111
Reliability coefficient, α	0.7502433032

The results of the survey were converted into graphs and charts. The results of the first question showed that most of the respondents were from Comala. Besides, the data of the second question showed that the people who frequent public spaces were mainly young adults, representing 71% of the respondents.

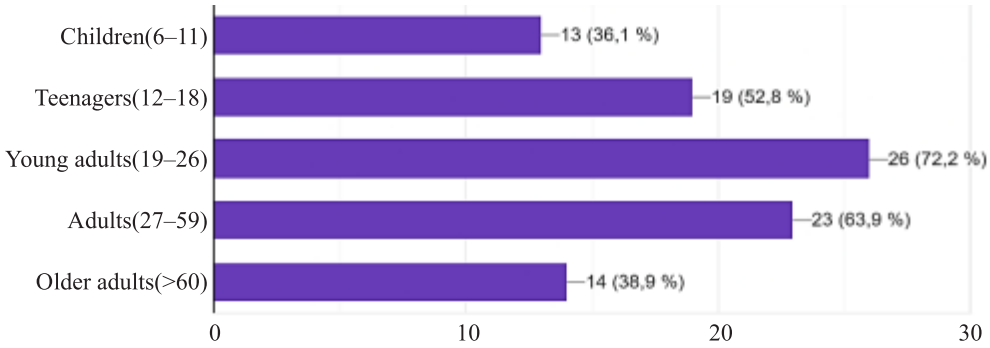


Figure 2. Results of Question 2 of the survey

Questions 3 and 4 were the last questions of the first section, which were open-ended, so their results varied. The answers to these questions showed that cleaning brigades were among the most popular community-based activities for this population.

Based on the answers to Question 6, the aspect that was of the greatest importance in the integral development of the community was infrastructure, with 58.3% of the respondents selecting it, followed by space maintenance with 41.7%, security with 41.7%, and safety with 41.7%, accessibility with 27.8% and, lastly, vegetation with 5.6%. Besides, based on the responses to Question 10, the three priority areas for improving the community are infrastructure at 80.6%, security at 63.9%, and accessibility and maintenance, both at 61.1%. As for Question 11, 82.9% of the population highlighted vegetation as the greatest virtue of their space.

In Question 12, the assessment of the current state of natural reserves showed a mix of responses, with 52.8% rating it as good and 33.3% as fair. Regarding the condition of neighborhoods, according to Question 13, there was a tie at 61.1% between infrastructure and security, followed by maintenance at 50%. Accessibility stood at 22.2%, and vegetation lagged at 8.3% (**Figure 3**).

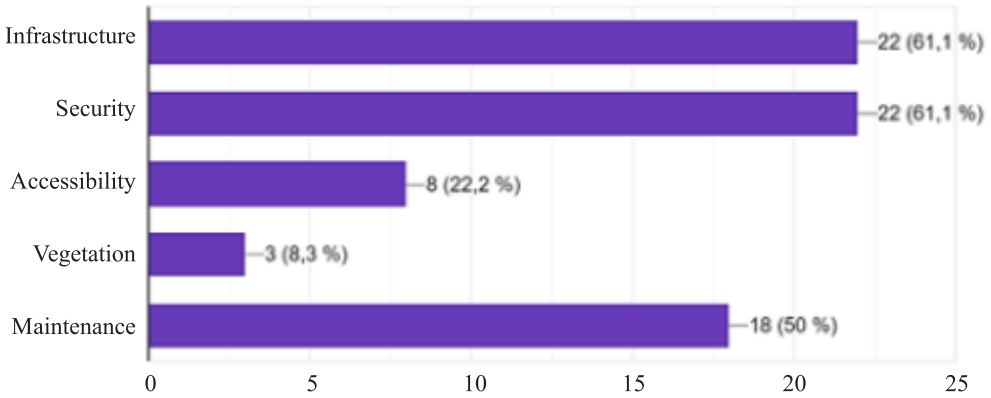


Figure 3. Results of Question 10 of the survey

Question 14, which was the last question in the qualitative section, addressed the issue of adequate infrastructure in public spaces for emergencies. Most of the respondents categorized it as fair and poor, with 71.4% of the population agreeing with this opinion.

Question 15 marked the beginning of the quantitative questions section. Question 15 reveals that 41.7% of the population currently participates in activities related to their community, with 25% participating very frequently. On the other hand, 33.3% of the population were less involved in those activities, mainly due to misinformation or lack of publicization.

For the result of Question 19, there were only two types of responses. 77.8% of the population considered promoting harmonious development in their community to be very important, while the remaining 22.2% considered it important.

The responses to Question 22 varied. 38.1% of respondents started participating in community-based activities one month ago. People who participated for a week, a year, and more than 2 years all accounted for 14.3% each.

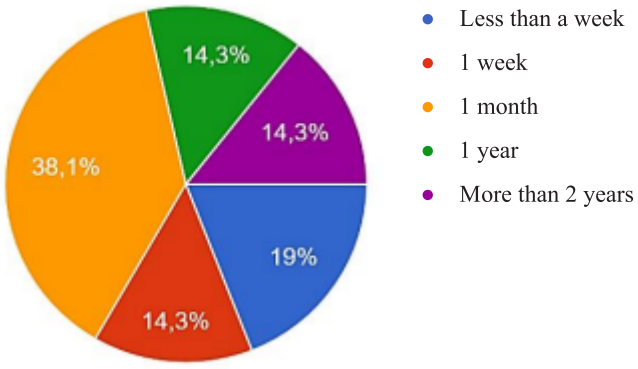


Figure 4. Graph of the results obtained in question fourteen of the survey

In Question 23, the results show that 85.1% of the respondents have noticed an increase in housing in the periphery of their community, so they are very interested in this phenomenon. Meanwhile, the remaining 14.8% of the population seems indifferent or not interested in this phenomenon.

For Question 26, 8.3% of the respondent indicated that their communities organize group activities very often, 38.9% responded "often," 19.4% responded "sometimes," 30.6% answered "rarely", and 2.8% answered "never."

Question 27 addressed the accessibility of the space, where 22.9% of the population considered it very good, 41.7% considered it good, 30.6% considered it to be fair and only 5.6% considered it to be bad.

Question 28 addressed the street lighting in public spaces. 85.7% of the population ranked it from good to fair. 8.6% of those surveyed considered it to be very good, while 5.7% considered it to be poor. Question 29 addressed the safety of the space. There was a tie in the responses "good" and "fair." Meanwhile, 2.8% of the sample considered it to be very good and 5.7% considered it to be very poor.

Based on the responses to Question 30, more than half of the population, i.e. 57.1%, thought that the recreational areas were fair. 31.4% said it was good, followed by 5.7% who considered it to be very good. Lastly, there was a tie in the percentage of respondents that thought the recreational areas to be bad and very bad, both at 2.9%.

Question 31 required the respondents to rate the gathering points in their communities from 1–5. Half of the respondents rated their gathering areas with a 3. This indicates that the spaces are in fair condition.

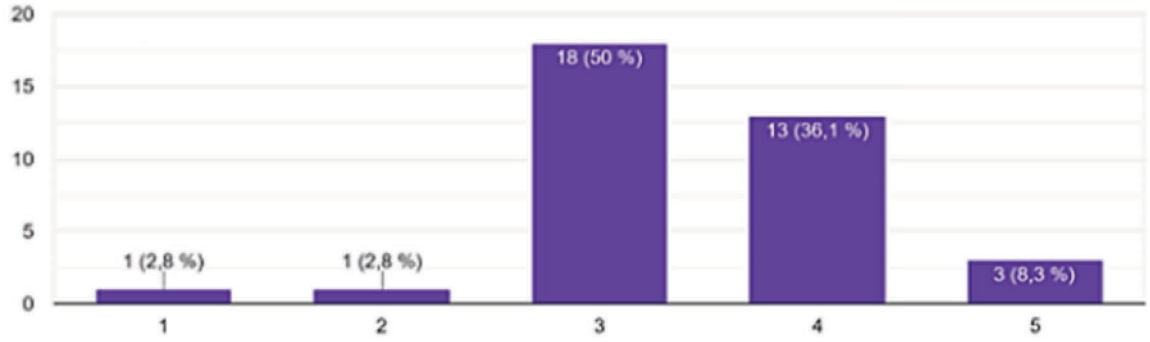


Figure 5. Results of Question 31 of the survey

Question 32 deals with the extent to which citizens' opinions are taken into account by the authorities in charge, and a wide variety of results were obtained. The most noteworthy aspect of this topic is the contrast of the voters' answers. 30.6% of respondents thought that their opinions were taken into account to a great extent, while 27.8% of respondents said that their opinions were not taken into account at all.

Question 33 referred to the perception of citizens regarding the decisions made by the municipal government in their urban environment. Specifically, 38.9% agreed quite a bit. However, 27.8% of voters felt somewhat disconnected from the decisions made, while 19.4% expressed uncertainty about whether their opinions were taken into account or not.

In Question 34, the effectiveness of information dissemination was addressed. Results showed that 16.7% found it highly efficient, 30% considered it fairly informative, 25% were unaware of the information, 25% had limited information, and 2.8% of the population had no idea about the situation at all. This suggests that deficient information dissemination was more apparent compared to adequate dissemination. In Question 35, respondents were asked about their perception of their neighborhood. The most common response was feeling quite vulnerable, representing 38.9% of the total sample. This was followed by 33.3% who were unsure how to define their experience of living in their neighborhood, 19.4% of the population indicating they felt somewhat vulnerable, and finally, 8.7% of the population reported feeling not vulnerable at all.

Question 36, the last quantitative question, was related to community safety. A majority, comprising just over half of the sampled population (58.3%), indicated feeling somewhat insecure in their surroundings.

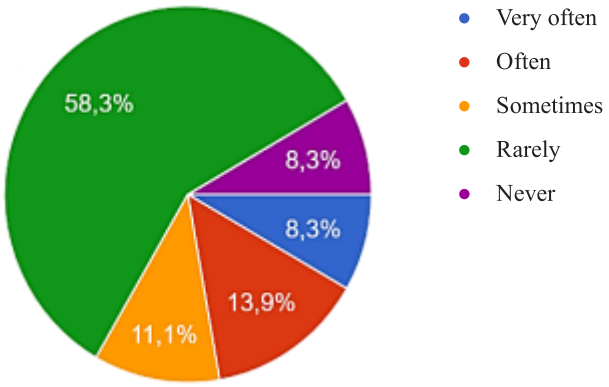


Figure 6. Pie chart of the results of Question 26

4. Conclusion

Based on the results of our survey on citizen participation, we can conclude that the majority of respondents were interested in participating in decision-making and fostering harmonious urban development in their community in the municipality of Comala. However, less than half of the sample participated regularly in group activities related to their community, practically every month, and fewer people felt that their opinions were taken into account. Nevertheless, they largely agreed with the government's decisions for the benefit of their community. In other words, despite the low actual participation, the population approved of the municipality's management. The responses reflecting the prevailing trend indicated that the priority areas for improvement in public spaces and urban settings in Comala were infrastructure and security, followed by space maintenance. The majority were in favor of supporting the comprehensive development of the community. Consequently, they believed that public spaces were not adequate for accommodating the population in case of an emergency while acknowledging urban vegetation as the greatest virtue of their environment. It was inferred that, although public spaces were aesthetically pleasing to residents, they were aware of the infrastructure deficiency, except for public lighting, which was deemed to be in good condition. Furthermore, most respondents had observed a significant increase in housing on the outskirts of the city; however, less than half perceived themselves as vulnerable, despite the high levels of insecurity.

Based on the aforementioned findings, valuable insights have been gathered to incorporate into the diagnostic process for the development of Comala's Municipal Urban Development Program, with an emphasis on citizen involvement. It is recommended to complement the proposed survey with additional tools, such as community workshops, throughout the diagnostic and strategy formulation stages of urban and architectural development aimed at enhancing the municipality's social progress.

Moreover, the survey yielded specific and valuable insights, thus accomplishing the intended objective of this research. We gained a clear understanding of the survey's effectiveness, which was validated through statistical techniques and the Cronbach's Alpha formula, with a reliability percentage exceeding 75%. The survey can be used in other population centers and municipalities across the state to compare results, refine its effectiveness, and enhance it based on identified areas for improvement. By replicating this process, we can contribute to designing programs and strategies aimed at promoting citizen participation and enhancing the quality of life in the municipalities of Colima.

Disclosure statement

The authors declare no conflict of interest.

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Appendix

Answer the following survey. 1 is the minimum and 5 is the maximum in questions involving the scale of 1 to 5.

Respondent information

1. What is the name of the community where you live?

2. Who visits these spaces?

Children	Teenagers	Young adults	Adults	Older adults
(6–11 years old)	(12–18 years old)	(12–26 years old)	(27–59 years old)	(> 60 years old)

3. Could you mention any activity promoted by the city council regarding citizen participation in which you have participated in the past?

4. Could you mention any decision-making activities for your community in which you have participated recently?

Qualitative questions

5. Why do you not participate in activities related to your community?

I participate I don't know I am not interested Others

6. In your opinion, what aspects of public spaces in your city would you improve?

Security Infrastructure Accessibility Vegetation Maintenance

7. What are usually the social gathering spots within your community?

Gardens Churches Sports centers None

8. What happens most in the places where people gather?

Public events Private events Acts of vandalism

9. In ascending order where 1 is the least important and 5 is the most important, what aspect do you think is the most vital in the integral development of your community?

Security	Infrastructure	Accessibility	Vegetation	Maintenance
(___)	(___)	(___)	(___)	(___)

10. From your perspective. Point out 3 options that your community needs to improve.

Security Infrastructure Accessibility Vegetation Maintenance

11. Indicate three characteristics that your community does have. .

Security	Infrastructure	Accessibility	Vegetation	Maintenance
(___)	(___)	(___)	(___)	(___)

12. How do you consider the current state of green areas and nature reserves in your community?

Very good Good Fair Poor Very bad

13. In ascending order where 1 is the least important and 5, what aspects of the city's neighborhoods need improvements?

Security	Infrastructure	Accessibility	Vegetation	Maintenance
(___)	(___)	(___)	(___)	(___)

14. Does the community have adequate infrastructure to house people in case of emergency?

Very good Good Fair Poor Very bad

Quantitative questions section

15. On a scale of 1 to 5, how interested are you to be in public/collective affairs?

1 2 3 4 5

16. On a scale of 1 to 5, how interested are you in participating in decision-making on urban issues that affect citizens of your community?

1 2 3 4 5

17. How much do you participate in associations or entities of any kind, whether cultural, neighborhood, sports, or political?

1 2 3 4 5

18. How often do you participate in activities related to your community that are organized by the municipality of Comala?

Very often Often Sometimes Rarely Never

19. Do you think it is important to promote harmonious development among the communities within the municipality of Comala?

Very important Important Neutral Not very important Not important

20. How much have you heard about activities aimed at people's participation in decision-making promoted by your municipality or government?

1 2 3 4 5

21. How much have you participated in activities that serve your community recently?

1 2 3 4 5

22. How long have you been involved in activities that serve your community?

Less than a week (1) One week (2) One month (3) One year (4) More than two years (5)

23. In your opinion, how much do you think that the housing areas in your community have increased over the years?

1 2 3 4 5

24. What is your position on population growth in your community?

I'm very interested I'm interested I'm neutral I'm a little interested I'm not interested

25. Do you consider the growth in the number of homes and inhabitants in your community to be good or bad?

Very good (1) Good (2) Neutral (3) Bad (4) Very bad (5)

26. How often do the members of your community gather for group activities?

Very often Often Sometimes Rarely Never

27. How accessible is this place to the public?

Very good Good Fair Poor Very bad

28. How is the public lighting in this area?

Very good Good Fair Poor Very bad

29. How is the security of this space?

Very good Good Fair Poor Very bad

30. How are the recreation areas in this space?

Very good Good Fair Poor Very bad

31. On a scale of 1–5, how would you rate your community's meeting spaces?

1 2 3 4 5

32. Are the opinions of the citizens taken into account by your city council in making urban decisions?

Very much Quite a bit I don't know A little Not at all

33. To what extent do you believe that your city council facilitates citizen participation in the decisions it makes?

Very much Quite a bit I don't know A little Not at all

34. Do you currently believe that your municipality provides adequate information on how to participate in urban decisions that affect citizens?

Very much Quite a bit I don't know A little Not at all

35. Do you consider the neighborhoods in your community to be vulnerable in terms of the urban context? That is, if these spaces are at a disadvantage compared to those with better services.

Very much Quite a bit I don't know A little Not at all

36. How involved are you in neighborhood activities with that serve your community?

1 2 3 4 5

37. Is the community perceived as unsafe?

Very much Quite a bit I don't know A little Not at all

Appendix 1. Survey questionnaire

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The Limits of Domestic Spatiality in the Information Age – A Secondary Publication

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Abstract: The limits of spatiality have blurred in the information age; a phenomenon that can be observed through the socio-spatial implications of Internet use in the domestic sphere. How and why are the use and organization of space-time around the Internet shaping a new domestic spatiality that intertwines the digital space with the production of social space through the practice of habits, presence, and interaction of individuals? What are the repercussions of the superimposition of digital space on human existence? The units of analysis were integrated through the sum of people and middle-class housing in the face of the digitalization process in the city of San Luis Potosi, Mexico. The questionnaire consisted of 35 questions designed from the Likert scale under the thematic order of presence, interaction, and habituality. The data were analyzed using SPSS software. This research contributes to explaining the current period in the history of inhabitable space, dominated by the simultaneous interrelationships between individuals, digital space, and architecture, which result in the detachment and devaluation of physical domestic space, while also highlighting the lack of control and regulation of individuals over the Internet.

Keywords: Graffiti; Urban image; Legislation; Regulations; South America

Online publication: February 26, 2024

1. Introduction

The transformations of domestic spatiality are manifested through the new forms of spatial production characteristic of the 21st century, as a result of the way we perceive, think, and act within the space-time of the digitized home. Spatiality is a manifestation within the process of cultural configuration and is constantly redefined due to the different ways in which it is the various ways in which space-time is used, organized, and given meaning. Although human thinking and acting, according to Clifford Geertz, are produced as a public act and are only secondarily considered as an intimate matter and private matter [1], the Internet confuses this order and leads us to dwell on the margins of extinction of physical space, rapidly affecting spatial practices by abruptly incorporating itself into the intimate sphere of the home, thanks to its capacity to accommodate and integrate into all human activities.

The domestication of the internet involves integrating digital space into the household. This creates a new

space, originating from technology and science, that parallels the three dimensions of involvement in everyday life as proposed by Roger Silverstone for television: cultural transformation, communication system, and reality definition [2]. Within this new culture, it is defined as a large information system, including humans and their activities [3]. Thus, some of the main changes brought about at the domestic scale by this phenomenon are the alteration of human presence through the fragmentation of attention, the re-signification of space-time, the lack of control over the force of habituality exerted by the digital space, and the modification in the way people and objects interact in the home.

This is due to the fact that space-time is currently understood as a commodity and hides the social relations within its production scheme. In particular, it "conceals the contradiction of the coexistence of homogenization and spatial fragmentation, as well as the tendency to its totalization and atomization simultaneously" [4]. Here it is proposed that new domestic spatialities are now produced simultaneously and immediately through a process of fragmentation of private and public dimensions at both local and global scales. This redefines people's daily lives, distances, and chronological sequence of traditional daily activities, which are on the brink of disappearing. Thus, spatial production appears in a schizophrenic manner, in the sense that it alters the awareness of reality, and displaces people's orientation and attention in space-time due to the condition of simultaneity and the illusion of ubiquity. This phenomenon generates a new conception of space and a hybrid way of inhabiting the house, akin to wandering among fragments of labyrinths in a state of permanent wakefulness between physical and digital space, diminishing the value and importance of physical space.

Within this context, living in the information age is directed more towards the consumption of data, goods, and services; more toward superficial communication than to the construction of face-to-face personal social relationships and to the care of what constitutes the being of individuals – the presence and interaction of people in the home.

The home, as a space meant to accommodate the relationships and social practices that define spatial production in everyday life, seems to be disappearing, replaced by the digital space that concentrates activities unrelated to the domestic sphere, compressing and exposing it. This new layer of social space has become intertwined with established spatial and behavioral patterns in 20th-century spatiality. This leads to questioning whether contemporary everyday life lacks the stability provided by rituals and customs, which are forms of knowledge belonging to the home [5]. Through rituals, things and time-space are neither consumed nor spent, but used [6]. In this way, the digital space is becoming the universal vehicle through which the understanding of the globalized world is mediated, dividing as much as uniting, and also in how people understand and relate to it [7]. Therefore, it is essential to explain from architecture the implications of the overlap of the digital space in the space-time of the home through changes and continuities in habits, patterns of behavior, forms of communication, distance between people, time spent online, and level of internet dependence; as well as through changes in the meanings attributed to places by new ways of living together and the new activities incorporated into the home as a result of its digitalization.

2. Habituality, interaction, and presence

To address spatiality in the information age, in which there is a transition from a heavy industry-based economy to a service-oriented economy with the needs of the service-oriented economy with the needs of the consumer at the center, domestic spatiality is explained through a theoretical model of three main categories that account for how space-time is used and organized: habitualness, interaction, and presence [8]. These three realities shape the different spatialities and domesticate space-time through the daily uses it is given; uses that are deeply

and constantly influenced by emerging and dominant communication systems. Specifically, the way we think, abstract, and communicate meanings within the social structure of the family is an act inscribed in the act of inhabiting that is manifested through architecture [9]. Firstly, habitualness enables the modification of people's material existence through transformations arising in representational spaces due to the intensive use of the internet. Thus, the recurrence of practices becomes a habit in the process of configuring spatiality [5]. Habits shape different ways of life and are also present manifestations of the spatiotemporal mutations originated by the technological and social conditions of a given period. The use of space takes on its temporal dimension through habituality, which, in turn, redistributes and diversifies people's actions and habits within the process of assimilation and resistance initiated, in this case, by the emergence of a new communication system, the internet. The greater the influence of habituality on daily life, the lower the degree of awareness of subjects about the details of existence, which are veiled by routine activity. Thus, habituality is defined as a force that lies precisely in the invisibility, familiarity, conditioning, and power exercised by the instituting society. It is a power that is practiced through space-time and resorts to the family as an institution for its production and reproduction.

Secondly, interaction implies corporeality, contiguity, and distance between people and the domestic object system of objects; it integrates emotions and feelings, gives rise to the tensions and conflicts generated by the domestication of the internet, as well as the contradictions between proximity and isolation caused by the overlapping of digital space in the home. Human interaction involves dialogue, giving voice to the other and simultaneously constructing a self; it brings together and disposes subjects for the production of space through action, intersubjectivity, and otherness. The active subject appropriates space-time and inhabits it; they do so alongside others, with others. In this way, dialogue becomes the vehicle that activates and animates the presence of interaction, composed of polysemic gazes and voices; gazes that either facilitate or avoid dialogue, filling space-time with silence or emptying it. Interaction carries meanings of existence through corporeality, which is the quality of being that allows access to material and symbolic experiences with others.

For both Maurice Merleau-Ponty and Alfred Schütz, the body represents a means of communication and relationship with the world in which language is essential; because, thanks to corporeality, the internal and external worlds are organized [10]. For Niklas Luhmann, the structural coupling between consciousness and communication is embodied through language, which has developed acoustic forms; and in the case of writing, optical forms that draw attention to consciousness and at the same time convey communication [11]. For Henri Lefebvre, language is constructed from the immediate: the body, sensation, impulses and practical activities, memory, and spontaneous relations [12].

Martin Heidegger asserts that the exhortation of the essence of a thing comes to us from language, on the assumption that we pay attention to its essence [13]. Given these conditions, the domestic spatiality is constructed intersubjectively to understand and interact with the other through the body and language, within a process of distancing/un-alienating, embodying consciousness in space-time. Thus, the importance of the body itself is not that of an object of the world, but as a means of our communication with it through architecture.

Thirdly, presence is characterized by something being present in time and space, ready to enable and provide room for action. In this sense, presence grants individuals a propensity associated with the act of creation through poiesis [13]. The presence of ourselves to ourselves is consciousness, and our body is embodied consciousness that opens to the world creating an inseparable unity in space and time [14]. This immediacy is not symbolic like representations, which easily enter the internet as a dominant communication system. This means that the study of presence, as part of the process of configuring spatiality, plays a fundamental role in explaining how actions unfold in the presence of individuals. This means that the study of presence, as part of

the process of configuring spatiality, plays a fundamental role in explaining how actions unfold in the presence of individuals. Presence predisposes people to the acts of daily life that unfold as a mode of temporality and constitute the original sense of being, of being-there [13]. Presence is in itself the vehicle for communicating through corporeality; it allows interaction in space through the temporality exercised by habituality. Beyond this, presence, from its physical dimension, uses the body as an instrument to perform acts of everyday life in the perceived space, in architecture; and from its symbolic dimension, presence resorts to the imagination to operate from the lived space and deepen the search for new possibilities of spatial reality. From this perspective, presence allows for the appropriation of space-time and "turns space into places by adapting them, using them, transforming them, and pouring on and into them the affectivity and imagination of the inhabitant, giving them their playful and symbolic dimension" [4]. This is how being present in the home evokes existence, which, through the use of domestic space-time, integrates habituality, interaction, and presence. Therefore, the purpose of this paper is to reflect on the utilization and arrangement of space-time in contemporary times and highlight the impact it is exerting on the bond between individuals and their living environments.

3. Methodology

The approach strategy to the studied reality was defined as non-experimental conclusive. The objective was to find links and associations between the categories from which the phenomenon is approached, understood as a correlational/causal process. For the study of changes and continuities in this process, it was necessary to interrelate the previously exposed categories: habitualness, interaction, and presence, to obtain the necessary information to explain the transformations of the domestic space. For operationalization purposes, the home was integrated as the unit of analysis by summing up the individuals and middle-class households in the city of San Luis Potosí, Mexico, undergoing digitalization. On one hand, the middle class is the social stratum that, besides having the purchasing power to hire internet service and possess various personal digital devices, plays a determinant role in shaping society. On the other hand, their homes are architectural objects that fulfill a determined architectural program that establishes, from the physical space, a series of possible preconceived relationships, according to the type and number of people using the different spaces within it. In this study, the architectural program, resolved in constructions of 145–225 m^2, consisted of 3–4 bedrooms, 2 ½ bathrooms, a living room, a dining room, a kitchen, a TV room, a service room, a service patio, a garden, and a garage for 1–2 automobiles.

The study encompassed all households in the city of San Luis Potosí that met these selection criteria and also had internet service. the population was defined by selecting 42 Basic Geo-Statistical Areas (AGEBs), primarily because the largest concentration of internet-connected households is situated to the west of San Luis Potosí. This area predominantly consists of medium to medium-high-density residential zones, catering to middle-class households on lots ranging from 144 m^2 to 249.99 m^2, totaling six thousand one hundred eighty households. The sample size was determined by considering the various stages of the household life cycle and its 11 different configurations [15], as well as the four housing typologies specified in the Building Regulations of San Luis Potosí Municipality, Mexico. Addresses were randomly selected for the administration of the survey instruments.

The questionnaire consisted of a total of 35 questions and was divided into three sections. Each contained a series of questions that represented the sequence of the interview under the thematic order of presence, interaction, and habituality. The interview began with four open-ended questions, followed by 24 questions designed on a Likert scale, and concluded with seven open-ended questions. This instrument sought to narrate

the everyday life of the families from the individual and collective, through the perception of their daily life, interaction, and presence in the domestic environment. The information obtained was processed and analyzed using SPSS software. The objective was to understand how people produce their space in the information age and the value they place on physical and digital spaces. Therefore, it was possible to reveal, from the subjects' point of view, the current daily life, by comparing different moments of the presence of digital space in the home.

4. Results

4.1. A new domestic space

The home is a place of learning, a practical space in constant movement for social production and reproduction. According to the findings, domestic spatiality in the information age generates the idea of home generated by the digitalization of the habits, interactions, and presence of individuals. The knowledge of the world and the establishment of places occur from the coexistence between digital and physical space. People are learning to situate, interact, and orient themselves through social practices that go beyond the understanding that the individual knows the world in an isolated and static way [16]. Therefore, people give meaning and value to the relationships they establish with others and with objects through everyday practices in the digitized home.

These changes in family dynamics inevitably transform people's understanding of the domestic environment and the way they relate to the world. The members of a family, individually and collectively, constitute social structures and actively participate in their construction through their daily practices. These cannot be studied separately from the architecture and the lived space because it is there that the changes in the use of space-time of the social body. Therefore, analyzing what is happening around and within us during this period allowed us to discover how the digital space is imposing itself as a new area of the home. Our data showed that the four stages (adolescents, young adults, middle-aged, and elderly) agree that the internet is a new space within the home, and the size of physical spaces is no longer as important if access to the network is available.

While the domestication of digital space began in the late 20th century, wired connectivity to the internet and the speed of digital devices restricted the spaces and times in which the network could be accessed. The domestic spatiality of that time was characterized by programming and sequentiality. Similarly, interaction and the presence of people were differentiated between the private and the public, the interior and the exterior, and the home and the non-home. In the third decade of the 21st century, connectivity expands wirelessly throughout the house, allowing the overlay of the digital space through the personal portability of digital devices. Currently, the entire house is permanently connected to the digital space, enabling people to move from one space to another and engage in multiple activities simultaneously in physical and digital space, regardless of the time or place these activities take place in daily life. The results of our study showed that the level of control and regulation over the use of the internet is virtually non-existent, and disconnection from the digital space causes anxiety in people.

Digital space now contains and produces society's representations, models and lifestyles, behaviors, and global trends in what is erroneously instituted as real time.

Digital space, under this approach, is consumed and consumes us as we relate to each other in and through it. In itself, it is a new domestic space, a product of the technology introduced into the home; a place in which our new understanding of the world is articulated. Today, the family environment is surrounded and revolves around the activities that are carried out through smartphones, tablets, and computers [17]. The familiarity with which we interact with and through these portable devices prevents us from easily recognizing that beyond the Internet as a medium, what underlies is the relationship of dependence of people with the digital space and its detachment from the physical space. It has also instituted the false belief of ubiquity and timelessness.

Our data indicate that, for the time being, the conscious action of the subjects within the process of overlapping digital space and the domestication of the Internet is limited and passive. In most cases, there is a high degree of ignorance in general about the Internet and particularly about what its domestication represents for the family space-time, with its value often assessed solely based on utility and convenience. As long as the connectivity and service quality meet expectations (such as uninterrupted connection, full coverage, and high speed), there is little concern about this new household space, as long as it enables a prolonged digital presence.

Therefore, it is essential to be aware of the implications of coexisting in physical and digital spaces simultaneously. Without realizing that we are doing something significant, the everyday, the habitual, and the little things that make up our existence give meaning to architecture and form part of the history of inhabitable space. It is crucial that each moment becomes something wonderful in itself, to the point of justifying existence, life, and inhabiting [18]. Otherwise, and without the need for physical contiguity in digital space, presence, which is existence embodied in space by means of social relations governed by mysticism and imagination, is at risk [4].

5. Conclusion

This moment in the history of domestic inhabitable space is crucial because, within different family structures and life cycle stages, there are still those who remember life before the internet, alongside young people and children who do not know any other way of interacting and communicating with others inside and outside the home. This study establishes that the force of habit determines and accommodates a multiplicity of spatialities in the information age. All of them share the pressure to digitize the maximum number of human activities and detach from physical space according to the degree of control and regulation over the internet. This level of action is determined, initially, by the stage of the family life cycle and the group to which one belongs; however, it was found that the force of habit has instituted a common mode of spatiotemporal use, shared by the diversity of spatialities; a mode that involves architecture but also transcends it.

Domestic spatialities share the difficulty and lack of regulation of intensive use of digital devices from fixed spaces and schedules at home; a phenomenon originating from the domestication of 3G phones connected to the network, Wi-Fi technology, and Web 2.0. Additionally, this condition is directly related to media imposition and social pressure to incorporate digital devices into the domestic object system.

Today, the idea of the home as the center of the individual world of each person, which flows back to childhood, needs to be rethought under the conditions provided by the digital space, as home is easily lost, and reclaiming it is a tough journey [19]. his is even more relevant now, as the home, as a space of alterable centrality and relative orientation granted by people and their habitual practices, has paradoxically contracted and expanded its territoriality, modifying its socio-spatial meanings through the unregulated superposition of the digital space.

This study confirms that the current domestic spatiality is shaped by two key factors: Firstly, there’s a growing separation between physical proximity within the home and the execution of daily activities, which are increasingly conducted through digital spaces. Secondly, there’s a transformative ability to redefine experiences by blurring the boundaries of architecture and digitizing social practices. As a result, individuals now derive a sense of belonging more from digital spaces than from physical ones, where their events and repetitive actions unfold in the context of a global society.

Consequently, the study of spatiality in the information age is fundamental for the habitat sciences. Since, in the words of Edward T. Hall, it is a serious mistake to make as if the human being were one thing; and his house, his technology, and his language, were another [20]. It is precisely the conscious exercise of spatiality that integrates the existence of the subject through the inhabiting of space-time. Therefore, the spatiality in the

information age should be further studied to better understand what is happening and what the domestication of space represents for our society.

Disclosure statement

The author declares no conflict of interest.

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Study on the In luencing Factors and Mechanisms of the Evolution of the Architectural Characteristics of Guangfu Ancestral Halls in the Ming and Qing Dynasties

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Abstract: This paper discusses ancestral hall architecture within the context of the Cantonese folk lineage in the Pearl River Delta. Using a typological research approach and chronological analysis, various factors that have influenced the evolution of ancestral hall architecture are analyzed. The study specifically investigates the features of ancestral halls during the Ming and Qing dynasties. Three periods of ancient China are analyzed: The transition from Ming to Qing, the mid-Qing dynasty, and the late Qing dynasty. The variables of each period and how they influence the evolution of architectural typological features are identified. Based on our analysis, architectural features are related to economic and social factors, materials available, and craftsmanship of the construction workers.

Keywords: Guangfu ancestral halls; Architectural type characteristics; Evolutionary influences; Evolutionary impact mechanisms

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1. Introduction

Ancestral halls are temples where clansmen worship their ancestors and manage their clans [1]. The formation of ancestral halls is due to the long history of feudal patriarchal society. The family temple system was born in the Zhou Dynasty, only the royal family and nobility could build family temples and ancestral halls. In the Song Dynasty, *Chu Hsi's Family Rituals* advocated for the establishment of ancestral halls within families. During Ming Jiajing's reign, the *Tui En* Decree and the popularization of the *Book of Rites* made ancestral halls more accessible to commoners. Ancestral halls are also an abstract concept, encompassing both the architecture and cultural significance associated with them. The architectural characteristics of ancestral halls primarily encompass the building's size and spatial arrangement. Architectural elements encompass the building's appearance, form, and decorative features, all of which reflect the cultural significance of the structure. Additionally, architectural

materials and craftsmanship contribute to the texture and overall aesthetic of the building.

The term "Guangfu" was first used in the Ming dynasty, it refers to present-day central and western Guangdong Province and southeastern Guangxi Province [2]. In the socio-cultural context, Guangfu also refers to the Han Chinese people in the Lingnan region who use the Cantonese dialect [3]. In this paper, Guangfu refers to the Pearl River Delta (PRD) region centered on Guangzhou, and the main area of study is the "Nanfanshun Guangfu Core Area," the economic and cultural center of the PRD, i.e., the historical Nanhai, Panyu, and Shunde counties. The design of Guangfu ancestral halls is an art that combines local geography and climatic conditions for site selection, layout, and styling. According to their different functions and nature, they can be divided into four categories: ancestral halls, historical figure memorial halls, temples named after academies, and private temples or study rooms named after schools or study rooms [4]. During the Ming and Qing Dynasties, Guangfu ancestral halls underwent three peaks of construction, which can be divided into a period of shaping (late Ming and early Qing Dynasty), maturing (mid-Qing Dynasty), and mechanizing (late Qing Dynasty). The architectural type characteristics of Guangfu ancestral halls in different periods are obvious and follow certain evolution laws. This paper summarizes the epochal variables of the three periods, analyzes the factors affecting the evolution of the architectural characteristics of ancestral halls, and sums up the mechanism of the evolution of the architectural characteristics in each period.

2. Analysis of factors influencing the evolution of architectural characteristics of Guangfu ancestral halls in Ming and Qing dynasties

2.1. Late Ming and early Qing dynasties (shaping period)

(1) Social factors

In the third year of Ming Hongwu, the *Daming Rites* was repaired, and the system of ancestral halls in *Chu Hsi's Family Rituals* was generally accepted by the scholars, and the phenomenon of unauthorized building of ancestral halls had already appeared in the civil society. In the same period, the court through nomination, examination, and other ways to create the local gentry class, the local elders were included in the power system of the dynasty and made them become the main force of the management of the local [5]. With the promulgation of the *Book of Rites* and *Tui En* Decree during the Jiajing period of the Ming Dynasty, the ancestral halls of commoners were legalized. Consequently, many scholars in the Guangzhou region, while supporting the *Book of Rites* and Confucian rituals, also actively practiced the idea of respecting their clans in their hometowns. As a result, the number of ancestral halls increased significantly, giving rise to the first folk ancestral halls. This led to a peak in the construction of ancestral halls, with many featuring three halls and three openings [6,7]. Officials and eunuchs vigorously promoted the construction of the family system, and ancestral halls became a strong bond between clans, seen as a symbol of the "noble and prestigious families." The construction of ancestral halls was prioritized over residential buildings, and the establishment of family temples and the editing of genealogies were regarded as the embodiment of the importance of the clan. Ancestral halls played a dominant role in the pattern of villages, which to a certain extent helped villages form a relatively stable morphological pattern [1]. As the local gentry in Guangzhou Province dominated the social order of the countryside, the integration of family traditions and township covenants prompted the ancestral halls to take on the functions of ancestor worship and the preaching of sacred edicts and township covenants [8]. The *Sixteen Articles of the Oracle* promulgated during the Kangxi period of the Qing Dynasty and the *Sacred Oracle of the Guangxun* promulgated during the Yongzheng period both emphasized the clan as the basic institutional unit of the state and determined that the ancestral halls needed to take on the

functions of clan rituals, education, almsgiving, and the establishment of social ties.

(2) Economic factors

From the Hongwu period of the Ming Dynasty onwards, the commercialization of agricultural production in the Guangfu area of the Pearl River Delta, the prosperity of town markets [9], the development of maritime trade, the massive accumulation of wealth, and the proliferation of ancestral hall construction activities. During the Ming and Qing Dynasties, Guangzhou Province was plagued by wars and natural disasters. During the Kangxi period of the Qing Dynasty, the boundary was moved several times and the sea ban was enforced, so the Guangzhou Prefecture lacked the motivation and conditions to build ancestral halls in the turbulent situation, and the pattern of clan villages was destroyed, and the construction of ancestral halls was mainly repaired. In the middle of the Kangxi period of the Qing Dynasty, the government adopted a soft policy to restore economic development, redevelop coastal land, and reconstruct villages with issues related to settlement rights and development rights. In this event, large clans chose to gather together to proclaim the development rights of the Shatian, to rebuild or expand their ancestral halls, and to demonstrate the cohesion and prestige of their clan with one road with three entrances and five bays [1].

(3) Cultural factors

Before Zengde's reign during the Ming Dynasty, society was dominated by a culture characterized by frugality, childishness, melancholy, and conservatism. However, after the first year of Zhengde, there emerged a trend towards seeking variety and advocating novelty, with life becoming increasingly luxurious and extravagant. Consequently, ancestral halls expanded in scale, with decorative carvings such as scroll-like patterns and swirling clouds appearing on wooden and stone components [10]. Red was the most popular color at the end of the Ming Dynasty [11], and was therefore seen in many of the ancestral halls.

(4) Construction factors

During the Ming Dynasty, red sandstone from the Pearl River Delta was rich in resources, and mining techniques were developed, and it was widely used in architecture. Saltwater stones, consumable shells, and sea moons were easily accessible in the coastal areas and were also found in architecture [12]. Large quantities of hardwoods were procured from overseas to Guangfu for the production of supportive or decorative wooden elements. In the Wanli period of the Ming Dynasty, the fire brick technology was not yet fully developed. However, in economically advanced regions like Shunde, the quality of bricks was relatively high. During this era, the art of Guangpai woodcarving evolved into single-layer hollow carving and began to be widely used in architectural ornamentation and furniture decoration. Wars during the Ming and early Qing dynasties led to the advancement of iron smelting, the improvement of tools; and processing technologies for granite, green bricks, and other hard construction materials were developed. During the Kangxi period, the mining of red sandstone and saltwater stone, so granite was used instead for building construction.

2.2. Mid-Qing dynasty (maturing period)

(1) Social factors

During the Kangxi and Qianlong periods, the traditional clan-son system faced challenges in its implementation. Clans began to assess their status based on their social accomplishments [13]. Some smaller clans, residing nearby and sharing the same or different surnames, resorted to lotteries and divination to decide on common surnames. They organized virtual blood ties through cross-regional

temples[14]. The emergence of cross-regional temples led to the second climax of ancestral hall construction. With lenient state management, ancestral halls became more diverse in their layout, featuring structures like single-entry, triple-entry, and triple-ancestral halls.

(2) Economic factors

With the stable political situation during the Kangxi and Qianlong years, the development of the clan ancestral halls in the Shatian district brought the clans a stable income, and Guangzhou was in a position to monopolize foreign trade because of the Canton System, leading to the prosperity of the commodity economy [15]. The rapid population growth in the same period prompted the division of clan houses and the redistribution of property. Additionally, the increasing prosperity of small family economies led to the disintegration of large ancestral hall organizations, giving rise to a form dominated by small ancestral halls among the common people [16]. As the sizes of ancestral halls shrunk and shifted towards popularization and populism, the system of small ancestral halls became dominant [9]. The widespread popularity of three-room halls and gate schools led to the emergence of more complex social forms and spatial structures in clan villages. The revival of commerce promoted the development of handicrafts and modern industry, increased social mobility, strengthened the connection between rural and urban areas, and led to the appearance of cross-domain temples in cities, known as academies, examination halls, villas, and so on [8].

(3) Cultural factors

During the Qianlong period of the Qing Dynasty, the hierarchical division of ancestral halls and the rise of the commodity economy led to a growing self-awareness among the people. They began establishing “private taikongs” in their own names to showcase their achievements. Prevailing secular beliefs emphasized the importance of using the finest materials and techniques to erect grand shrine buildings, seen as a symbol of success for future generations. This mindset resulted in the construction of numerous intricately decorated shrines and mansions. Concurrently, Guangpai wood carving reached its pinnacle during this period, with noblemen’s fondness for “gold and blue” encouraging the widespread use of gold lacquer wood carving. This artistic expression combined painting and wood carving, featuring colors predominantly in yellow, green, and blue hues.

(4) Construction factors

Influenced by the ban on red sandstone and saltwater stone mining during the Kangxi dynasty and the advancement of granite mining and processing techniques, granite emerged as a popular alternative to wooden beams, which were vulnerable to erosion from rain. Granite became widely utilized in building construction. The maturity of hemp stone mining and processing technology followed later than that of granite, providing a basis for dating the construction periods of ancestral halls. Qing brick firing technology experienced further development, resulting in uniform color, relatively smooth surfaces, and smaller holes in the bricks. Brick carving techniques were introduced from northern regions and quickly adopted by the Guangfu Ancestral Halls. Additionally, Shiwan tiles, manufactured in Shiwan Town, were integrated with theatrical elements in their production, resulting in ceramic sculptures with striking decorative effects. The technique of crafting grey sculptures using lime emerged, primarily employed in the creation of roof ridges and walls.

2.3. Late Qing dynasty (mechanizing period)

(1) Social factors

In the first year of Xianfeng, the Taiping Heavenly Kingdom Movement swept across the country, and

the Taiping army burned down Confucian temples and palaces, denounced the Confucian scriptures as demonic, reduced the role of Confucianism as a rite of passage, which severely impacted the feudal landlord class and clan system. In order to reorganize the grassroots organizations and restore the order of local administration, the Qing government worked together with the people to revive the construction of ancestral halls based on blood relations and geography, leading to the third climax in the construction of ancestral halls [16]. In the first year of Guangxu's reign, the court relaxed its control over cross-regional temples, and there was no punishment for the construction of these temples, indirectly acknowledging their legitimacy, thereby increasing their number. Temples within the city expanded across regions, with grander scales and lavish decorations, featuring layouts such as "five halls, five corridors, three entrances," and various decorative crafts, displaying rich and colorful decorations. Some social charity schools established by clans, gentry, merchants, and overseas Chinese appeared in the form of cross-regional temples, with ancestral halls undertaking the function of local education [16].

(2) Economic factors

Stimulated by the Opium War and the Foreign Affairs Movement, the birth of national capitalist industries, the shift in the economic model drove a shift in urban-rural relations, with cities becoming centers of social and political influence, and geopolitical ties and interests drove the emergence of cross-regional temples in large numbers in the cities. Ancestral halls appeared in forms like "one hall, three corridors, three entrances" and "three halls, three corridors, three entrances," with extraordinary scales and distinctive architectural styles compared to the past [1].

(3) Cultural factors

The introduction of new Western ideas and the criticism of Confucian traditions led to many traditional rituals no longer being strictly observed in folklore, resulting in the emergence of numerous cross-regional temples with Western architectural elements and new materials such as cast iron [1]. The shift in social aesthetics during the same period drove the wooden beams to evolve from moonbeams to set panels for carved paintings, realizing the transition from the poetic to the mundane.

(4) Construction factors

The development of architectural technology led to the emergence of mechanized production, and ancestral halls began to be constructed more systematically. The technology for firing blue bricks had become increasingly mature, and regions with developed economies and commerce had better-quality blue bricks. Brick carving technology experienced unprecedented development. Stone carving technology became increasingly mature, and stone components featured special carving techniques, with stone figures on the front eaves becoming fashionable.

3. Analysis of the mechanisms influencing the evolution of building-type characteristics

3.1. The impact of economic and social factors on architectural forms

Economic conditions are the material basis for the construction of ancestral halls. When society and the economy are stable, the construction of ancestral halls is frequent, the scale is enlarged, and the decorations are gorgeous; when economic development is hampered, the construction of new ancestral halls becomes stagnant, and repair work becomes the focus. Dynastic and social changes affect the state of economic development to a certain extent, when the country is in a period of war and turmoil, economic development halts; when the country is in a period of rest and recuperation, the imperial court promulgates many policies to promote economic development, which will in turn drive the construction of the ancestral halls. At the end of

the Qing Dynasty, the development of national industry and the revival of commerce led to the prosperity of the commodity economy, which on the one hand promoted rapid population growth and the prosperity of the small family economy; on the other hand, it changed the relationship between the urban and rural areas, and the development of the cities led to the birth of cross-regional temples. Therefore, it is clear that economic and social factors contribute to the development of ancestral halls in terms of scale and morphological features of ancestral halls.

The court's attitude towards the patriarchal system and the measures taken to manage it also had a greater impact on the evolution of ancestral halls. The legalization of ancestral halls for the common people was promoted by the *Book of Rites* of the Jiajing period, the weakening of state control during the Kangxi and Qianlong periods contributed to the drastic changes in the form of ancestral halls, and the government's strategy of not penalizing the construction of previous cross-regional temples in the first year of the Guangxu period reflected the legitimacy of the cross-regional temples. Hence, this shows that ancestral halls' forms are influenced by economic and social transformations, and also imperial administration.

3.2. The impact of construction and social factors on the architectural materials and craftmanship used in ancestral halls

The selection of the main building materials for ancestral halls is related to the type of local resources and the maturity of mining and processing technology in the area where the ancestral halls are located. Considering the cost of manpower and material resources, most of the materials used for construction are mainly from local resources that are large in quantity, easy to obtain, and have mature processing technology, and only a very few influential clans can purchase and transport expensive building materials from overseas.

Social factors also influence the choice of building materials and craftsmanship for ancestral halls during special periods. Red sandstone and Saltwater stone are indigenous geological resources of the Pearl River Delta and are widely used in building construction. However, under the influence of the Kangxi dynasty ban, granite and hemp stone successively replaced these two materials. During the Daoguang period, with the defeat of the Opium War and the spread of the Western Movement, Western architectural ideas and techniques were introduced to traditional ancestral halls, leading to the adoption of Western-style building materials and construction methods in the halls.

3.3. The impact of cultural and construction factors on architectural decorative features involving cultural significance

The decorative patterns and colors of the buildings reflect the social culture, prevailing customs, and aesthetic trends of the time. In the traditional concept, the richness and splendor of ancestral halls is a reflection of the talent and social status of the descendants. In the middle of the Qing Dynasty, the development of Guangpai woodcarving reached its peak, and the love of the dignitaries for "splendor" promoted the use of gold lacquer woodcarving on a large scale. In the late Qing Dynasty, after the return of Chinese sons and daughters who had left their ancestral land to stay in the ocean, the sons and daughters of overseas Chinese, in order to show off their noble status, constructed ancestral halls that embodied the shape of beautifully decorated ancestral halls that were rich in cultural connotations. On the whole, as the social atmosphere gradually tended to be more certain and extravagant, the decorations of ancestral halls became more and more complex and rich in variety.

The development and maturity of decorative crafts such as wood carving, brick carving, and stone carving also promoted innovation in architectural decoration. Wood carving craft in the Ming and Qing dynasties has been developed many times, from the simple door, and window decorative wood carvings to bright-colored camel dun figures and gold lacquer wood carvings, it can be seen that the architectural decorative craftsmanship

technology of the growing mastery of the ancestral halls affect the degree of exquisite architectural decoration.

Cultural and construction factors complement each other and jointly influence the characteristics of the decoration of ancestral halls, making the decorative elements of the Guangfu ancestral halls architecture of the late Qing Dynasty of high aesthetic and artistic value.

4. Retrospect and prospect

The Ming and Qing Guangfu ancestral halls can be divided into three main stages of development: the forming period in the late Ming and early Qing Dynasties, the maturing period in the mid-Qing Dynasty, and the programming period in the late Qing Dynasty, with distinctive characteristics of the times. The evolution of the architectural form of Guangfu ancestral halls is tied to the characteristics of the region and the era, and the joint influence of social, economic, cultural, and construction factors. This study clarifies the influence of specific variables on the architectural features of ancestral halls in the three periods of the Ming and Guangfu clans and concludes that the architectural form features are mainly influenced by economic and social factors, the architectural material and craftsmanship features are mainly influenced by construction and social factors, and the architectural decorative features are mainly influenced by cultural and construction factors.

The Pearl River Delta, as an economically developed region, saw traditional ancestral halls suffer destruction and neglect during the rapid process of urbanization. In recent years, with the increasing attention to the protection of historical and cultural heritage by the state, restoration activities for ancestral halls have reached their peak. The results of this study, which analyze the factors and mechanisms influencing the architectural evolution of Guangfu ancestral halls during the Ming and Qing dynasties, have theoretical significance for guiding the preservation and restoration of traditional Guangfu ancestral halls in different periods. They provide support for the revitalization and utilization of traditional Guangfu ancestral halls.

Disclosure statement

The authors declare no conflict of interest.

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A Review of Innovative Design Strategies for Prefabricated Green Buildings

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Abstract: Prefabricated green buildings are becoming a trend in the construction industry of China. The prefabricated components are made using modern technologies like green materials, artificial intelligence, and low-carbon and energy-saving techniques. This makes them an important aspect of the development of the construction industry in China, representing modernization and sustainable development. This article presents a study on the innovative design of prefabricated green buildings. This article serves to promote sustainable development on a macro level.

Keywords: Green prefabricated building; Monolithic residence; Waterproof and anti-seepage; Bathroom caisson

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1. Introduction

Prefabricated green buildings can significantly promote energy conservation, emission reduction, and maximum utilization of resources in the construction industry. In this way the sustainable development goals can be achieved and environmental pressures can be alleviated. Prefabricated green buildings align with ecological civilization, which is advocated by the country [1]. Therefore, engaging in innovative research on prefabricated green building design drives the development of the construction industry in China, elevating its status on the international stage in terms of building construction.

2. Overview of prefabricated green buildings

2.1. Prefabricated green building

The development of prefabricated green buildings is essential in the modern construction industry. The concept of prefabricated green buildings is built upon the core concepts of prefabrication and green buildings, which consider both construction efficiency and environmental friendliness [2]. Green design and the application of green technologies are important aspects of building prefabricated green buildings. This form of building construction serves to achieve energy conservation and emission reduction, thereby reducing pollution and achieving the maximum recycling of resources. By doing so, the negative impact of building construction on

the environment can be reduced [3].

2.2. Characteristics of prefabricated green buildings

Prefabricated green buildings are characterized by their high efficiency and energy-saving properties, sustainability of material and resource utilization, improvement of indoor environmental quality, intelligent management, etc., as shown in **Figure 1**.



Figure 1. Characteristics of prefabricated green buildings

(1) High efficiency and energy saving

The components of prefabricated buildings can be manufactured in a factory, which only improves construction speed and quality but also significantly reduces the problem of material waste.

(2) Sustainable materials and resource utilization

Prefabricated green buildings are made using renewable resources and low-pollution materials, which can significantly reduce their negative impact on the environment during the construction process, which in turn helps maintain biodiversity and ecological balance [4].

(3) Higher indoor environmental quality

The design of prefabricated green buildings emphasizes the optimization of indoor air quality, lighting, temperature, and humidity to create a relatively healthy and comfortable living environment for users.

(4) Intelligent management

The application of building information model (BIM) and the Internet of Things (IoT) can achieve intelligent resource management in the design, the construction, and the use of the building. Besides, the energy consumption of the building equipment (such as electromechanical and HVAC systems) and building maintenance costs can be reduced [5].

(5) Reduction of life cycle costs

The entire life cycle of the building is emphasized in the design of prefabricated green buildings, including the construction, use, and maintenance stages, and even the renovation and demolition stages. Therefore, compared with traditional cast-in-situ concrete buildings and prefabricated buildings, prefabricated green buildings reduce long-term operating costs and help achieve economic sustainability [6].

3. Advantages of prefabricated green buildings

3.1. Improving building performance

Prefabricated green buildings are usually made of materials with better thermal efficiency and structural stability.

Prefabricated building components are manufactured in a controlled environment, making the components produced more precise. Therefore, the components have better sealing and insulation effects, which reduces heat loss and energy consumption. Secondly, prefabricated buildings are usually made of lightweight materials, which can significantly reduce the weight of the building while still ensuring its safety and durability. Lastly, renewable materials used in prefabricated green buildings and the consideration of environmental friendliness during the design phase are highly beneficial to the physical and mental health of the residents.

3.2. Optimizing architectural design construction processes

By adopting a highly modular and standardized design concept, the entire project can be implemented more systematically, and uncertainty and risks during construction can be reduced. During the design stage, BIM can be used to simulate and analyze the building for further optimizations. BIM technology can create a four-dimensional model of the design to ensure a high degree of alignment between prefabricated components and on-site installation. Besides, refined manufacturing processes and technical standards allow high-quality construction and reduce rework and material waste [7].

4. Research on innovative design of prefabricated green buildings

4.1. Innovative design for integrated housing

Under the concept of reshaping future building construction, the innovative design of integrated housing in prefabricated green buildings can start from the four dimensions of system structure, modular design strategy, innovative application of integrated technology, and intelligent management system.

When it comes to optimizing structural systems, the modularity and standardization of the building should be prioritized in the design. Architects can achieve a variety of component combinations and quick assembly through detailed component segmentation and universal interface design. Adopting this new systematic design model simplifies the manufacturing and installation process and facilitates maintenance and upgrades, effectively extending the service life of the building. In addition, the modular design strategy can also flexibly adapt to changes in the needs of users and owners during the design and construction phases, achieve flexibility in building space and layout, and meet the need for a personalized living space in buildings [8].

Second, the optimized design of the prefabricated green building structure can also be highlighted through integrating technology. In residential designs, designers can integrate new environmentally friendly materials and clean energy technologies. For example, solar panels can be installed on the roof to power the heat pumps to achieve energy self-sufficiency and reduce overreliance on external energy. At the same time, high-performance insulation materials can be used for doors and windows during the design stage to optimize the thermal efficiency of the building further and maintain indoor comfort and energy-saving effects.

Finally, integrating intelligent management systems can create an innovative living experience for integrated residential buildings. Real-time monitoring of indoor environmental parameters, including temperature, humidity, carbon dioxide, and PM2.5 values, can be achieved through built-in sensors and intelligent control systems. The building's indoor heating, ventilation, cooling, and air purification will then be automatically adjusted based on the values of the aforementioned parameters.

4.2. Innovative design for building waterproofing and impermeability

Innovative designs for waterproofing and anti-leaking in prefabricated green buildings can be achieved through integrated designs such as external wall insulation and waterproofing, as well as polymer waterproofing.

Integrated external wall insulation and waterproofing prevent leaking by combining insulation materials

with waterproof layers, forming a seamless and continuous protective layer for the exterior walls. The waterproof systems in traditional buildings often suffer from thermal bridging, which is caused by the separation of the insulation and waterproof layers. Therefore, the integrated design of the thermal insulation layer material and waterproof membrane can be constructed simultaneously to form an integrated organic protective layer. This strategy can improve construction efficiency and prevent leaking due to poor construction.

Polymer waterproof coatings are utilized in prefabricated green buildings for the waterhouse and underground garage areas, creating a highly elastic and strongly adhesive waterproof membrane. This waterproof membrane can adapt to minor deformation caused by thermal expansion and maintain the integrity and sealing of the waterproof layer for a long time. Besides, polymer coatings can compensate for the risk of leakage caused by tiny, uneven joints, especially for the joints of assembled components.

4.3. Innovative design for embedded parts

Embedded parts play a key role in prefabricated green buildings. They are an important link in connecting various prefabricated building components and significantly impact structural safety, stability, and construction efficiency. The innovative design of embedded parts can focus on improving project quality and construction speed while ensuring the long-term performance of the structure [9].

The corrosion of embedded parts is a key consideration during the installation stage of reinforced concrete components that would seriously affect the quality and stability of the building. To prevent corrosion of the embedded parts, red lead can be sprayed on the parts. Red lead is an effective protective material due to its good rust resistance and adhesion. It forms a protective layer on the surface of embedded parts, effectively isolating moisture and oxygen, which prevents them from being corroded by water vapor.

Round-head embedded nails should be used to further improve the stability of embedded parts. Compared to traditional flat-head nails, the arc-shaped head of round-head embedded nails can provide a larger contact surface and increase the anchoring force, strengthening the connection between them and the concrete.

4.4. Innovative design of prefabricated bathrooms

Prefabricated bathrooms mean that all components of the bathroom are prefabricated in the factory in advance and only need to be hoisted into place and connected on-site, thereby achieving rapid construction and excellent quality control.

(1) Modular design

The bathroom, as an independent spatial unit, can achieve highly integrated production through modular design, ensuring stability in construction quality and project duration. In the modular design stage, in addition to the fixed structural components of the prefabricated green building, it should also cover pipes, wires, and sanitary ware.

(2) Optimization of bathroom waterproofing and soundproofing performance

Waterproofing and soundproofing should be emphasized in designing toilets. Polymer waterproof coatings, sealing tapes, and materials with good sound absorption properties can be used to achieve those effects.

(3) Integrated design of bathroom structure and functions

The bathroom should be stable and equipped with intelligent equipment like smart toilet bowls, smart lighting, automated ventilation systems, etc. To ensure the smooth integration of various intelligent systems, designers should pay attention to reserving corresponding spaces and interfaces in the structure so that the equipment can be quickly installed during the construction phase and seamlessly

connected to the smart home system.

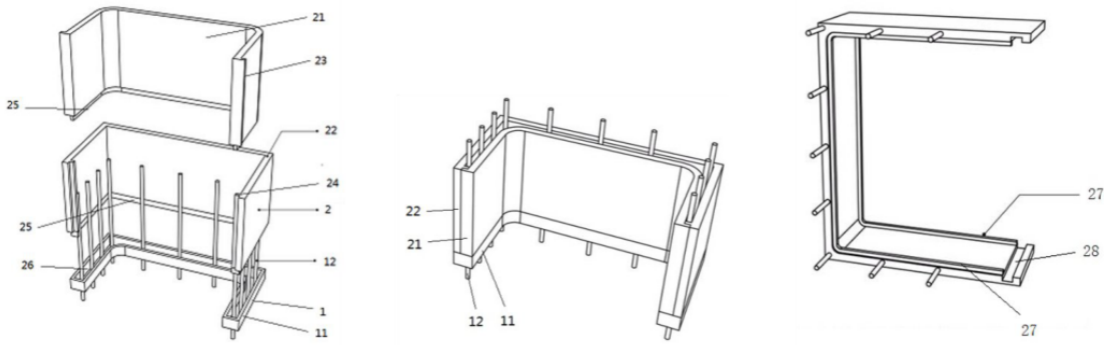
(4) Strengthening the overall style design

The appearance of the bathroom should also be consistent with the overall design of the building. The prefabricated bathroom caisson should also be seamlessly integrated into the overall system of the building. This requires a proper selection of materials and colors, and the functional layout, indoor layout, and user habits should also be considered during the design stage [10].

4.5. Innovative design of modular grouting mold

The main purpose of designing modular grouting tools for prefabricated green building construction is to address the shortcomings of previous prefabricated building wall panels, such as low modularity, poor workmanship, high prefabrication costs, and long production cycles.

The base and modular mold can be designed from bottom to top based on the modular grouting mold. The base would adopt a U-shaped design and a part of the steel bars would be embedded in the base. The modular mold includes an inner wall and an outer wall. The shape of the mold is the same as that of the base. The steel bars will be encapsulated within the inner wall and outer wall of the hollow wall (**Figure 2**).



Structure breakdown Overall structure The second and third grove

Figure 2. Schematic diagram of modular scratch-off mold

As shown in **Figure 2**, Part 2 of the prefabricated base would be processed through casting. The 12-part combination has both the advantages of steel bars and concrete. The concrete can be manufactured using sand and gravel or concrete wastes to reduce costs and material waste. The 12 steel bars are wrapped in a concrete protective layer, which is not prone to rust and has good corrosion resistance. The base and the modular grouting grinding tool are both detachable structures. Parts 21 (inner wall) and 22 (outer wall) of the grouting mold are also detachable structures. On Part 21, there are 23 horizontal grooves. The horizontal edge of Part 22 is designed to be similar to groove 21 on the inner wall. Part 24 (corresponding clips) is designed to fit into the bottom of Parts 21 and 22, as well as Part 25 (outer edge), to lock into base 11. The upper surface of base 11 is designed with Part 26 (grooves) corresponding to the protruding outer edge of Part 25. Two opposite inner walls of Part 27 are designed. A third groove (Part 28) is designed along the grouting direction to be inserted into the support plate during the operation stage.

Modular molds can be created based on user needs. Walls, columns, and beams are connected through grouting to form prefabricated wall components. During the pouring and molding of wall components, functional components such as internal lighting, doors and windows, and thermal insulation walls can be added based on built-in multi-functional channels. Using this module for prefabricated green building wall panel

construction ensures not only aesthetically pleasing structures but also easy operation, high recyclability, and flexible installation. This approach can greatly reduce the construction costs of prefabricated components.

5. Conclusion

Prefabricated green buildings have become an inevitable trend in China's construction industry. These types of buildings combine the advantages of prefabricated construction and green building practices. They can achieve ecological sustainability and cost savings while significantly improving construction quality and performance. Therefore, construction companies and architectural design firms should actively explore design innovations for prefabricated green buildings. New technologies should be integrated into the design and construction processes to better meet residents' needs and enhance environmental and economic benefits. Lastly, prefabricated green buildings allow the fulfillment of personalized user requirements and contribute to the overall green and sustainable development of China's construction industry.

Disclosure statement

The author declares no conflict of interest.

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A Review of the Key Points in the Design of Small-Radius Curved Ramp Bridges

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Abstract: This article explores the fundamentals of small-radius curved ramp bridges. It covers the selection of box girder spans, support methods, and forms, along with design optimization techniques for this type of bridge structure. The purpose of this paper is to provide robust support for enhancing the design quality of these bridges and ensuring their efficacy in real-world applications.

Keywords: Bridge design; Small-radius curve ramp; Box girder span; Support method; Support form

Online publication: February 26, 2024

1. Introduction

When designing a small-radius curved ramp bridge, its stress characteristics should first be clarified. Then, its box girder span and support can be designed accordingly. Lastly, its design should be further optimized through in-depth research based on actual engineering practices. In this way, the quality of the design can be improved and the requirements are met.

2. Stress characteristics of small radius curved ramp bridges

The main stress characteristics of small radius curved ramp bridges include the following: (1) The stress on the inner and outer sides is not uniform. The torque on this structure causes problems such as the inner beam unloading and the outer beam overloading, resulting in uneven stress on the inner and outer sides. (2) These bridges also suffer from flexural deformation. Under the superposition of twisting and bending, this type of bridge has greater deflection deformation than a straight bridge with the same span. (3) The structure is subject to transverse horizontal forces due to factors such as the horizontal centrifugal force experienced when a car is in motion, longitudinal horizontal forces resulting from temperature changes, and those arising from concrete shrinkage and creep. These forces act laterally, potentially affecting the stability and integrity of the structure. 4) Under a bending moment, the total cross-sectional stress of this type of bridge structure will be greater than that

of a straight bridge, making it more prone to deformation at the cross-section.

3. Key points in the design of small radius curved ramp bridges

Since the structure of a small-radius curved ramp bridge is significantly different from traditional straight bridges, its stress conditions are more complex, making quality control more difficult. Therefore, when designing such bridges, designers should take into account their characteristics [1]. The key points in designing this type of bridge project include several aspects: the selection of the span of the box girder, the selection of the support method, and the design of the support. Through proper selection of design contents and design methods, the quality of the design can be ensured. **Figure 1** is a schematic diagram of the overall structure of a small radius curved ramp bridge project (unit: m):

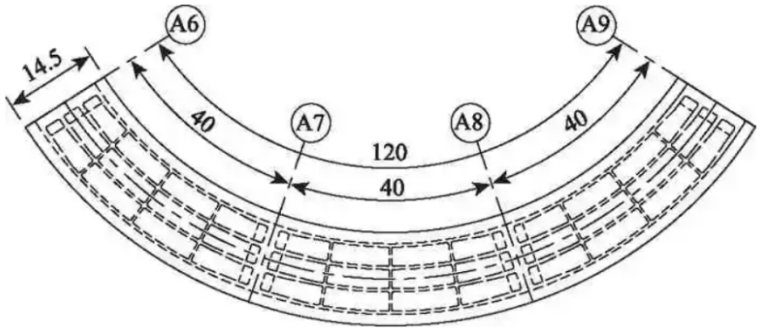


Figure 1. Schematic diagram of the overall structure of a small radius curved ramp bridge project

Below is an outline of the basic design points of the small radius curved ramp bridge.

(1) Selection of box girder span

The selection of a box girder span is crucial in designing a small-radius curved ramp bridge. Normally, such a structure's bending moment stiffness ratio will directly impact the structure's stress and deformation. If the bending stiffness is relatively high, the torque deformation caused by the curvature factor will also be relatively large [2]. Therefore, when designing this type of bridge structure, designers need to minimize its bending stiffness and improve its torsional stiffness while effectively controlling its vertical deformation.

To achieve this goal, the box section of the box girder should have a larger torsional moment and a smaller height. Generally, the span-to-beam height ratio should be around 18:1. Under certain conditions, the ratio of span3-to-beam height might need to be adjusted to 22:1. In this way, the span of the box girder can be adapted to the overall structure, thereby effectively avoiding deformation problems caused by the unreasonable span of the box girder and achieving reasonable savings in construction costs.

(2) Reasonable selection of support methods

In the structural design of small-radius curved ramp bridges, if different support methods are selected, the effects on the internal forces in the upper and lower structures will also greatly differ [3]. There are two main types of supports for this type of bridge structure: torsional support and point hinge support. The main components of these supports are usually basin rubber bearings or plate rubber bearings.

The type of support should be selected based on the structural parts of the bridge and actual working conditions. (i) Torsion supports are usually preferred in designing the ends of continuous beams to ensure higher lateral torque performance and lateral stability of the main beam. (ii) Either a

torsion support or a point hinge support can be adopted for the middle part of a curved bridge. Most component supports should use round plate or basin rubber bearings to effectively accommodate the lateral deformations of the main beam [4]. (iii) When designing a tall single-column mid-pier structure, it is important to consider implementing a pier-beam consolidation structure based on the specific situation. This approach effectively utilizes the bridge's flexibility, meeting deformation requirements while saving costs during construction.

(3) Layout of the support structures

The layout of the support structures is also important in designing small-radius curved ramp bridges to ensure their functionality, stability, and safety [5]. Support layouts for bridges commonly fall into three main types: all supports arranged as torsion-resistant supports, end supports as torsion supports with the middle support as a single pivot hinge support, and end supports as torsion supports with the middle support as a combination of single pivot hinge and torsion supports. Regardless of the chosen support form, designers must ensure that the lower piers are appropriately matched to maintain the overall bridge's support effectiveness.

However, it is no longer common to have double-bearing torsion bearings at both ends and several point hinge bearings in the middle. Therefore, when designing the support layout of such structures, designers usually choose the internal and external eccentric support layout plan. Prestressed steel tendons allow the gradual increase of the torque as the bending radius decreases, so the torque increases as the span increases [6]. To achieve this goal it is essential to consider several aspects when arranging the eccentric bearings at the mid-span of such structures. (i) To prevent lateral load uniformity, the eccentricity of the middle pier can be reasonably set to counter adverse effects caused by the bridge structure. For structures with a bending radius exceeding 130 meters, it is crucial to control the eccentricity within the range of 0.1 to 0.2 meters. (ii) To prevent the prestressed beam torque from affecting the bridge structure, the eccentricity of the mid-span supports can be increased. The total eccentricity of the mid-span supports can be determined based on the total eccentricity and resistance of the bridge, considering the sum of torques during prestressing. Designers may also arrange the mid-span bearings as inner eccentric bearings and outer eccentric bearings, strategically increasing the eccentric distance. This ensures uniform reaction forces from the torsion-resistant double bearings at the bridge ends, with slightly larger reaction forces from the outer bearings if necessary. (iii) To prevent adverse effects such as temperature variations, creep, and uneven torque, a fixed support should be installed at the mid-span of each curved beam structure or a consolidation pier at the mid-span to avoid bridge support slippage. (iv) When the overall stiffness of the bridge structure is low, supports can be strategically arranged at both the inner and outer eccentric parts to mitigate potential issues such as large stress on the inner edge or corner problems under vehicle driving loads [7]. (v) To prevent cracking of the bridge pier's top beam due to excessive reaction force from external bearings and avoid potential traffic accidents, double bearings or consolidated piers can be strategically arranged within the curved box girder structure of such bridge projects. Additionally, prestressed steel tendons should be carefully placed in the beams at the top of the pier, or the density of steel bars at the top should be appropriately increased. **Figure 2** is a schematic diagram of the finite element calculation and analysis model of a small radius curved ramp bridge structure.



Figure 2. Schematic diagram of the finite element calculation and analysis model of a small radius curved ramp bridge structure

In this way, the rationality of the structural support layout of small-radius curved ramp bridges can be ensured, thereby improving the design and construction quality of such bridges and minimizing the risks of accidents and problems caused by poor design.

4. Design optimization of small radius curved ramp bridges

Small radius curved ramp bridge structure exhibits a more complex stress situation. Therefore, compared to traditional straight bridge structures, designing this type of structure is inherently more challenging. To further improve the design of this type of bridge structure and meet its construction, application, and development needs in modern bridge engineering, in-depth research should be conducted on the optimization of its design. With the optimization of its structural design, the overall quality and safety of the project can be improved [8].

Several measures can be taken to optimize the design of such bridge structures. (1) The calculation and analysis of the overall bridge structure should be strengthened. Structural calculation and analysis are an indispensable part of bridge design. Designing such bridges typically involves calculating and analyzing torsional shear stress, torsional warping normal stress, and load forces under normal conditions. To improve the efficiency and accuracy of the calculations, designers can utilize advanced finite element analysis software. By establishing calculation models, importing relevant engineering data, and conducting finite element analysis, various parameters in this type of bridge structure can be accurately analyzed. By doing so, structural optimization can be achieved, ensuring the rationality of design parameters and scientific optimization of the overall bridge engineering structure design. (ii) On-site investigation of the construction site should be carried out. Only by fully understanding the actual conditions at the site and basing the structural design on this information can the overall structure have enough adaptability to meet the real construction and application needs of this type of bridge structure [9]. Therefore, before designing the bridge an on-site investigation of the construction site should be carried out, including items like hydrological conditions, geological conditions, climatic conditions, etc. A comprehensive on-site investigation facilitates material selection, parameter determination, and construction equipment selection. (iii) Utilizing advanced technology for construction and application simulation is essential. After determining its main parameters, simulations of bridge structure

construction and application should be carried out to ensure the quality of the design and its practicality [10]. BIM technology enables the simulation of construction and application for the bridge. By importing the designed bridge structure parameters into BIM software, a three-dimensional digital model of the bridge structure can be created. Subsequently, simulated construction and application of small radius curve ramp bridges can be conducted based on this model. This approach facilitates the timely discovery of design flaws, allowing for optimization and prompt adjustments to the design plan. Ultimately, this process enables the reasonable optimization of the design of this type of bridge engineering structure, enhancing its overall design quality.

5. Conclusion

In summary, small-radius curved ramp bridges have become the most typical form of modern bridge engineering structures. These bridges pose unique challenges in design and construction compared to traditional straight bridges. Therefore, it is important for both the teams working on these projects and the designers to focus closely on their design process. They need to understand the most critical design aspects thoroughly. By doing so, they can create practical and sensible designs for these bridges. It is also crucial to adjust plans as necessary based on the circumstances. This ensures that these bridges are well-designed, meet the needs of actual construction, and perform effectively in today's world.

Disclosure statement

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Analysis of the Application of Span-Bridge Technology for Building Highway Tunnels that Go Over Solutional Caves

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Abstract: This article presents a real engineering project showcasing the application of span-bridge construction technology for building a highway that goes over a solutional cave. An overview of the project and the details of applying this technology in highway construction are provided. Besides, strategies for enhancing its construction quality are also proposed. The objective of this analysis is to improve the safety and quality of similar projects.

Keywords: Highway; Span-bridge technology; Cave penetration

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1. Introduction

Building highway tunnels that go over solutional caves is challenging considering the unique environment of caves. Span bridge technology offers significant advantages in these situations. Therefore, this technology should be applied according to the situation to achieve the best effect.

2. Project overview

The project involved building a highway tunnel over a solutional cave using span-bridge technology. The maximum depth of the tunnel was 450 m, its overall length was 5,300 m, its axial length was about 29 m, its vertical axial length was about 40 m, and its height was about 15 m. The tunnel had to penetrate a solutional cave. The natural slope of the cave was about 20°, and it contained a significant amount of groundwater. Throughout the entire cave area, there was severe water seepage, resulting in a high risk of water inflow and extremely poor stability of the surrounding rock. When the tunnel was dug to about 2,100 m, it encountered an unfilled cave that ran northeast-southwest. Due to the large depth and volume of the cave, the tunnel needs to run through the middle, and the water droplets from the cracks increase the risk of flooding. In addition, there is a large cavity in the tunnel, so conventional construction techniques cannot

effectively ensure the safety of its structure. To ensure the efficiency, quality, and safety of the tunnel construction when it penetrates the cave, the spanning bridge technology was used. This article analyzes the practical application of this technology in this project and its quality improvement strategies.

3. Application of span-bridge construction technology in highway tunnel construction

For such projects, during the actual construction process, the construction unit must first address the caves and then proceed with foundation construction, floor construction, and side wall top arch construction. The following outlines the practical application strategy of this construction technology in this project [1].

(1) Cave treatment

The first step of constructing the highway tunnel was cave treatment, which involved two segments.

The first segment was backfilling the arches and uneven surfaces of the cave with slag. This procedure was done to facilitate subsequent cave treatment and excavation processes. The tunnel debris was backfilled into the cave bottom to achieve a thickness of 1–2 meters and pre-pressure treatment was performed. During this process, a staff member was assigned to observe the surrounding rock to avoid accidents caused by rock collapse.

The second step was cave support treatment. After backfilling, shotcrete shoring was carried out to provide support for the cave walls. This process involved setting anchor rods and steel mesh to stabilize the rock wall followed by spraying concrete [2]. If the cave wall was relatively unstable, or there were weak layers, they were reinforced with I-beams, and grouting was performed to prevent the wall from collapsing. **Table 1** shows the main parameters involved in the cave treatment of this project:

Table 1. Main parameters involved in the cave support treatment

Serial number	Parameter	Measurement/Type
1	Shotcrete anchor support concrete strength grade	C20
2	Diameter of steel bars in steel mesh	Φ8mm
3	Anchor length	1 m
4	Hexagonal anchor rod	1 m
5	I-beam model for reinforcement	Type I16

(2) Foundation construction

The construction of the foundation is crucial for building highway tunnels that penetrate solutional caves. Therefore, the following measures were taken to ensure smooth construction.

The first is a site survey and construction stakeout. When the excavation reached the cave area, the whole construction process was halted, and a survey of the cave was carried out [3]. The survey involved drilling the sides of the cave, general observations, and outlining the location and profile of the cave. After the on-site survey work was completed, the construction unit relied on the specific survey results to carry out construction layout on the opposite side wall, including axis layout and centerline layout [4]. If the actual conditions at the construction site could not meet its layout requirements, the construction unit had to resort to laser beams for positioning treatment in the excavation section to ensure the overall effectiveness of the tunnel excavation construction.

The next step was side wall excavation. Since there is no platform set up in this construction

section, the incremental excavation method was used, which involved drilling and blasting the walls and long-distance filling. The opposite side wall was blasted subsequently to create a hole with a diameter of 2 m. After drilling and blasting, I-beams were installed at both ends of the tunnel according to the designed spacing [5]. Next, a blasting channel was constructed to facilitate subsequent blasting work. After the walls were blasted, supports were installed to complete the construction of the foundation, ensuring maximum efficiency, quality, and safety.

(3) Floor construction

Floor construction is also a crucial step in constructing such tunnels. The floor construction was divided into two processes: steel formwork construction and floor pouring.

There are two main types of steel bar formwork: free-edge side formwork and bottom wooden formwork. For the free-edge side formwork construction personnel first set up scaffolding and then fixed the bolster plate to it. Steel bars were arranged strictly according to the engineering design, with all bars prefabricated outside the tunnel. After inspection and confirmation, they were transported to the construction site and put into use. During this process, workers ensured that the bottom plate was 0.7m or lower than the scaffolding to facilitate subsequent guardrail installation and construction [6]. When the steel bars overlapped, the construction personnel ensured to make reservations according to the engineering design requirements to facilitate subsequent side wall pouring. As for the bottom wooden formwork, the construction personnel only needed to place the bolster plate directly at its designated location.

As for the floor pouring process, the concrete mixing station was set up at a suitable location. The concrete was mixed and transported to the location where it was to be poured using a tanker [7]. It is important to follow the designed ratio of ingredients for the concrete mixture and pour it onto the base of the tunnel with the correct method. During pouring, the concrete was transported directly to the pouring position through a bucket truck for layered pouring, and a plug-in vibrator was used to vibrate the concrete to ensure its density met the requirements for the concrete base of such tunnels. **Table 2** shows the main parameters involved in the concrete pouring process.

Table 2. Main parameters involved in the concrete pouring process.

Serial number	Project	Parameter
1	Concrete base plate thickness	220 mm
2	Thickness of concrete base plate layer when pouring	30 mm
3	Concrete strength grade	C35
4	The depth to which the vibrator was inserted into the concrete	5–10cm
5	Vibration time of a single vibrating point	20 s

(4) Sidewall and roof arch construction

After completing the construction of the concrete base slab and maintaining it for 28 days or more so that it reaches 80% of the desired strength, the outer lining side walls and roof arch were constructed. The construction of the side walls and the top arch mainly included the following aspects: (i) The scaffolding was installed on the bottom platform and the installation and construction of the side wall and top arch formwork steel bars were completed. Subsequently, a concrete pump was used to pour concrete for the side walls and roof arches, allowing the concrete structure of the roof arch and the outer lining side wall to be cast and formed at once. This facilitates the construction of reinforced

concrete boxes [8]. (ii) The segmented pouring method was adopted when pouring the outer lining of the side walls and roof arch. The concrete was poured along the direction of the overall tunnel axis. This ensured sufficient load-bearing capacity of the side wall scaffolding, thereby achieving good construction quality and safety [9].

4. Improvement strategies of span-bridge construction technology in highway tunnel penetrating solutional caves

(1) Geological survey of the construction site

To effectively ensure the construction quality, detailed on-site surveys should be conducted at the construction site. The survey should include geotechnical engineering conditions, hydrogeological conditions, climatic conditions, cave and fissure conditions, etc. In this way, we can have a scientific and comprehensive understanding of the actual conditions of the construction site, thus facilitating engineering design and construction plan formulation.

(2) Simulating on-site construction conditions

With the continuous development of science and technology, on-site construction simulation has become a measure of technology and quality control in many engineering projects. Especially for highway tunnels that run through solutional caves, the engineering unit can simulate on-site construction situations using BIM technology and software. This allows for evaluating the effectiveness of each process flow and construction technology in the specific design and management. Technicians can import relevant parameters into BIM software to create three-dimensional digital models, aiding in construction planning [10]. Subsequently, the bridge project's simulated construction will follow set procedures and process technologies in the model. This allows for the prompt identification and rectification of deficiencies in various technological processes or construction technology applications. This ensures timely and effective optimization of the overall construction process and technical solutions. Additionally, technicians can promptly detect quality and safety hazards in actual construction and formulate response strategies accordingly with the help of the simulated construction model. This provides strong support for ensuring the application effectiveness of process technology and improving overall project quality.

(3) Effectively improve the professional level of construction personnel

To maximize the benefits of advanced construction technologies and the quality of the end product, it is essential to improve the quality of the construction workers. To achieve this, the following measures can be taken: 1) They should be briefed about the technologies, links, and techniques that will be used before the construction starts. (2) The construction personnel should be given regular training, especially for novel construction technologies or equipment to improve their skills. (3) The construction personnel should be managed properly. Strict reward and punishment schemes should be implemented to ensure the best performance and avoid mishaps. By taking these measures, the quality of the end product can be maximized and construction can be performed safely.

5. Conclusion

In summary, when constructing highway tunnel projects that go over large unfilled caves, the use of span-bridge technology is recommended. Scientific and reasonable cave treatment and engineering support are crucial in constructing such tunnels. It is essential to develop a construction plan based on the project profile and

standards and implement reasonable technical measures accordingly. Additionally, conducting in-depth research and applying quality improvement strategies is crucial to enhance the application effects of various construction technologies and ensure overall project quality and safety. This approach creates favorable conditions for applying engineering technologies and effectively improves overall construction quality.

Disclosure statement

The author declares no conflict of interest.

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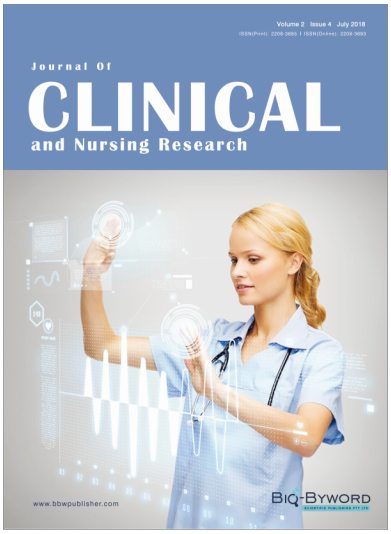
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