

A BIM-Based Visualization Model for the Protection and Digital Inheritance of Dong Architecture

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Abstract

Dong architecture is an important carrier of intangible cultural heritage. Its unique spatial structure and construction technology system contain profound cultural value. At present, faced with the realistic dilemma of traditional construction techniques being on the verge of being lost, cultural inheritance experiencing gaps, and the natural environment being damaged, effective protection paths need to be explored. This study proposes to use building information model and digital technology as the core to construct a visual protection model of Dong buildings, give full play to its advantages of information integration and three-dimensional visualization, and open up new ways for the digital protection of Dong buildings. The research carried out a systematic analysis around four key elements: information expression of cultural semantics, parametric modeling of wooden construction techniques, experience design of interactive communication, and collaborative sharing of multiple subjects, and then proposed a visualization strategy that integrates "modelling-protection-display-dissemination". This research aims to build a complete digital protection system for Dong architectural culture, provide systematic theoretical support and feasible technical solutions for the full-cycle digital inheritance of Dong architectural culture, and promote the digital protection and innovative inheritance of Dong architectural intangible cultural heritage.

Keywords: *Building information model, Intangible cultural heritage, Digital technology.*

Introduction

Dong architecture embodies ecological wisdom and collective memory passed down from generation to generation. Whether it is exquisite wooden construction techniques, harmonious spatial layout, or profound totem decoration, they all demonstrate this nation's understanding of nature and persistence of culture. With the advancement of the modernization process, these buildings carrying historical memories are facing double crises: on the one hand, structural damage caused by wind and rain erosion, and on the other hand, the skill gap caused by the aging of old masters and the departure of young people. In this context, Building Information Modeling (BIM) and digital technology provide us with new possibilities. This technology can not only record every mortise and tenon structure of the building, but also integrate non-material information such as construction technology and cultural meaning into the three-dimensional model. It is like establishing a "digital archive" for each building, which not only facilitates research and study by inheritors and intangible cultural heritage enthusiasts, but also allows more people to appreciate the unique charm of Dong architecture through three-dimensional display. This technical method is opening a new door for the protection and inheritance of traditional architecture.

Research background and significance

Cultural value and protection status of Dong architecture

As an outstanding representative of the traditional wooden architecture of China's ethnic minorities, Dong architecture is relatively concentrated in Guangxi. Among them, the Dong architecture in Liuzhou is represented by drum towers, wind and rain bridges and wooden houses. It has constructed an architectural cultural system based on wood and with group space as the core. Its structure adopts the mortise and tenon technique that combines passages and lifting beams to achieve excellent mechanical stability without the need for metal components, demonstrating the Dong people's high wisdom in the

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use of natural materials. In terms of settlement layout, the spatial pattern formed with the Drum Tower as the "heart of the village" not only undertakes the function of social organization, but also demonstrates the unique collective and ritual characteristics of Dong culture. In terms of aesthetic expression, decorative elements such as cornices, carved beams and painted buildings are organically integrated with the architectural structure, embodying the ecological concept of harmonious coexistence between man and nature.

Currently, this precious heritage, which carries the social order and cultural identity of the Dong people, is facing severe challenges: the flammable and perishable characteristics of wood make it extremely fragile in the face of natural disasters; the craftsmen who master traditional skills are old, and the younger generation is weak in their willingness to pass on, and the crisis of the inheritance of wooden structure skills is increasing day by day; the rapid urbanization process has caused irreversible erosion of traditional buildings and their cultural soil. These difficulties make the systematic protection of Dong buildings particularly urgent.

Application of BIM technology in architectural heritage protection

Del Savio Alexandre Almeida et al. (2022) proposed Building Information Modeling (BIM) as an integrated digital technology, which has attracted widespread attention in the construction field in recent years. BIM technology not only covers the geometric information of the building, but also includes the whole life cycle data such as material properties, construction process, maintenance management, etc., thereby realizing comprehensive digital management of building information. Durdyev Serdar, Mbachu Jasper et al. (2021) proposed that its core function is to improve the design efficiency, construction quality and operation and maintenance level of construction projects through the integration of multi-dimensional information such as three-dimensional modeling (3D Modeling), time management (4D) and cost control (5D).

From the perspective of technology development history, the evolution of BIM technology has experienced important changes from the initial application of computer-aided design (CAD) in the 1970s to the formation of a mature three-dimensional technology system in the early 21st century. In recent years, with the technology integration trend pointed out by Mehran Oraee et al. (2022), BIM has developed into a comprehensive digital platform integrating big data, cloud computing and the Internet of Things. Against this technical background, this study innovatively transformed qualitative research findings into quantifiable measurement research tools—specifically, through the axial coding stage of grounded theory, eight core categories (B1-B8) were extracted from the interview data and systematically transformed into a measurement index system in the quantitative research stage. Taking the category "Cultural Authenticity (B2)" as an example, we operationalized it into five Likert scale items such as "digital results truly reflect the creation skills", "completely present the cultural context" and "inheritor participation"; similarly, the "Perceived Usefulness of Technology (B1)" category was measured through four dimensions including "improving information management efficiency" and "promoting the visual dissemination of skills". This method of constructing measurement tools based on qualitative findings not only ensures a high degree of fit between the questionnaire items and the research phenomenon, but also provides theoretically based measurement standards for quantitative analysis, achieving a seamless connection between the qualitative and quantitative phases of the mixed research method.

Zhou Wei (2017) studied the application of BIM technology in the protection of Dong wooden building construction skills, and proposed that the efficiency and safety of protection work can be effectively improved through parameterization, visualization and consistency features. In addition, Zhang Jiajia (2020) analyzed the feasibility of combining AR technology with Dong architecture, emphasizing the potential of AR technology in the scientific preservation and interactive display of architectural resources. Lu Zhihua (2020) discussed the application of BIM technology in landscape architecture planning and design, demonstrating the comprehensive advantages of BIM+ technology in data acquisition, processing and model establishment. Li Benjian et al. (2023) took the Sanjiang Dong Drum Tower as an example, used digital acquisition technology to establish a database, and improved the communication effect through virtual three-dimensional technology and interactive media technology. The application of BIM and related technologies in the protection of architectural heritage not only contributes to the efficiency and accuracy of protection work, but also provides new ideas and technical means for the digital inheritance of cultural heritage.

Digital protection needs

Most of the current protection of Dong buildings mainly relies on traditional modes such as physical restoration, physical archiving and qualitative research. Although these methods have achieved certain results, they have obvious limitations: manual surveying and written records cannot meet the depth and accuracy requirements of conservation, the restoration process lacks accurate data support, paper archives cannot fully record the complex three-dimensional space and structural logic, and they are even less capable of recording and disseminating non-material attributes such as construction techniques and cultural rituals.

Liang Wei et al. (2019) analyzed the current situation of the architectural landscape in Chengyang Bazhai, Sanjiang, Liuzhou, and proposed the methods of "repairing the old as the old" and "building the new as the old" to protect the traditional architectural landscape in order to achieve sustainable development. In addition, Liu Hongbo et al. (2020) conducted an in-depth field investigation on the architectural protection of Dong villages in Sanjiang County, Guangxi, and pointed out that although the protection and repair of national-level cultural relics buildings are guaranteed, the control and improvement of the surrounding environment of historical buildings are different. Ye Yaxin et al. (2021) took the Fengyu Bridge in Sanjiang Dong Autonomous County as an example to analyze the problems and challenges faced in the protection and development of Dong architectural heritage, and emphasized the importance of active protection and inheritance. Zhang Jiajia (2020) studied the application of AR technology in the digital protection of Dong buildings and pointed out that in addition to traditional protection methods, AR technology provides a new way for the effective protection of Dong buildings. To sum up, as a precious cultural heritage, Dong architecture faces many challenges in its protection and inheritance. However, through multi-faceted efforts and collaboration, a virtuous cycle of protection and development can be formed to ensure that this precious cultural heritage can be continued and carried forward. Wu Yonghui et al. (2024) studied how to use digital technology and virtual media to protect and develop the architectural intangible cultural heritage of the Dong people in Sanjiang, Guangxi.

Faced with the multiple pressures of aging traditional building structures, loss of skills, and the impact of modern construction in the Dong area of Liuzhou, this traditional model of "emphasis on entities, light on information, heavy on static, and light on dynamic" has been unable to cope with the current complex conservation challenges. In this context, digital protection has become an inevitable choice for the inheritance of Dong architectural culture. With its core advantages of information integration, three-dimensional visualization, and parametric drive, BIM and digital technology provide a new way to solve the above dilemma. This technology can not only accurately record the dimensions of building components, mortise and tenon joint relationships and spatial layers through three-dimensional parametric models. Level logic provides a scientific basis for subsequent repairs and research. It can also integrate non-geometric information such as structural information, cultural semantics, and technical techniques to form a complete "digital asset" and realize the fundamental transformation of architectural protection from "form preservation" to "knowledge reproduction." In addition, through the combination of virtual display and interactive communication, BIM and digital technology can vividly reproduce the spatial aesthetics and craftsmanship spirit of Dong architecture, and effectively apply it to public education and cultural promotion, thus promoting the paradigm transformation of Dong architectural protection from static archives to dynamic inheritance, and providing key technical support for the living inheritance of cultural heritage.

Research objectives and significance

Research objectives

This study aims to construct a visual protection model of Dong buildings based on BIM and digital technology. Core content includes:

- to sort out the key factors for the inheritance and dissemination of digital Dong architectural intangible cultural heritage based on BIM.
- to integrated model construction strategy for traditional wood structure protection and visualization based on BIM technology.

Research significance

Theoretical significance: Promote the expansion of the role of BIM and digital technology from "engineering tools" to "cultural carriers" and inject new connotation into the theory of digitalization of intangible cultural heritage.

Practical significance: Provide a set of operable and popularizable digital solutions for Dong buildings to help them achieve permanent preservation, living inheritance and sustainable development.

Research Framework

Authors should clearly define their research design and methodology, detailing data collection and analysis techniques, while ensuring validity and reliability. Address ethical considerations, including approvals and participant consent, and acknowledge any study limitations

Research methods

Qualitative and quantitative mixed research methods

This study adopts a mixed qualitative and quantitative research method: through user testing and expert interviews, the application effectiveness of the prototype system is evaluated. This is a scientific choice based on the complexity and multi-dimensional characteristics of the Dong architectural BIM digital inheritance problem. It is difficult for a single research method to fully grasp the depth and breadth of this issue: although qualitative research can deeply explore the nature of the phenomenon, it lacks objective quantitative support; although quantitative research can provide statistical verification, it is difficult to capture the delicate changes in cultural inheritance.

The depth and breadth of research are unified through the design of "qualitative first and then quantitative". In the qualitative research stage, through in-depth interviews and participant observation, we systematically explored the influencing factors of the digital inheritance of Dong architecture, built a preliminary theoretical framework, and solved the exploratory question of "what key factors exist and their intrinsic structures". In the quantitative research stage, measurement tools are developed based on qualitative findings, and the causal relationship and degree of influence between factors are verified through questionnaire surveys and structural equation model analysis, and the verification problem of "how the relationship between factors is established and the intensity of its influence" is solved.

This iterative research design gives full play to the advantages of mixed methods: qualitative findings provide a theoretical basis for quantitative research, and quantitative results in turn verify and revise qualitative theories, forming a spiral research process. It not only ensures the realistic grounding of the theoretical model, but also improves the reliability and universality of the conclusions through large sample data, providing research results with both theoretical depth and practical value for the digital inheritance of Dong architectural BIM.

Data collection

In this study, data collection and analysis are key links in constructing a model of factors promoting the BIM digital inheritance of Dong buildings. In order to ensure the comprehensiveness and scientificity of the research, we adopted the data triangulation method proposed by Skrzypczak Izabela et al¹² which specifically includes three data collection methods: interviews, questionnaires, and literature reviews, and conducted in-depth mining and integration of the collected data through multi-level data analysis techniques.

The use of interview method aims to obtain in-depth insights from Dong architectural inheritors and relevant experts. We designed a series of semi-structured interview outlines, covering core topics such as the historical evolution of Dong architecture, technical characteristics, and the difficulties and opportunities of digital inheritance. The interviewees included Dong construction craftsmen, cultural heritage protection experts and BIM technology experts, a total of 6 people. The implementation of the questionnaire method aims to widely collect the opinions and attitudes of Dong village residents and practitioners. The questionnaire design follows a five-point Likert scale, covering dimensions such as awareness of BIM technology, acceptance of digital inheritance, and influencing factors. A total of 310 questionnaires were distributed and 310 valid questionnaires were recovered, with an effective recovery rate of 100%. SPSS software was used to enter and clean the questionnaire data to ensure the reliability and consistency of the data.

The application of literature review method provides a solid theoretical foundation for the research. We systematically searched relevant domestic and foreign literature on Dong architecture, BIM

technology and digital inheritance of cultural heritage, screened out more than 30 core documents, conducted content analysis and coding, and extracted key concepts and theoretical frameworks. Conduct qualitative data analysis through relevant software and construct a preliminary theoretical model.

In the data analysis stage, we adopted a multi-level and multi-dimensional analysis method. Through descriptive statistical analysis, the questionnaire survey data was initially processed to obtain basic statistics such as the mean and standard deviation of various indicators to reveal the overall characteristics of the sample. The factor analysis method was used to reduce the dimensionality of the questionnaire data, and the main factors affecting the digital inheritance of Dong architectural BIM were extracted, such as technical support, cultural identity, etc..

Analysis, Discussion and Results

Present analysis and results clearly and concisely, using visual aids where necessary. Results can be integrated with the discussion or summarized at the end

Qualitative research findings: Construction of promoting factor model

By conducting a grounded theory three-level coding analysis on the interview texts of six interviewees, this study gradually extracted the key promoting factors that influence the digital inheritance of Dong architectural BIM. In the open coding stage, a total of three initial concepts were obtained; through main axis coding, these concepts were summarized into three sub-categories and three core main categories. Selective coding analysis shows that these main categories form a closely connected theoretical model around the core story line of "how BIM and digital technology can effectively promote the inheritance and dissemination of Dong architectural intangible cultural heritage."

Spindle encoding

Line-by-line, sentence-by-sentence open coding of the text allows the identification and development of concepts and their dimensions and dimensions. First, similar events and situations are named and grouped into initial categories. On this basis, spindle coding is used to further summarize and integrate these initial categories, clarify the logical relationships between categories, systematize various scattered concepts to form a more core structure, find out the connections between different categories, identify the main category and its sub-categories, and gradually form the theoretical framework. The previous open coding produced a total of 27 initial categories. In the following, these initial categories will be further abstracted and summarized through axial coding to obtain the following 8 corresponding categories.

Table 1: Spindle encoding

Corresponding categories	Initial category
B1 Technology flooring barriers	A1 Software operation is complicated and difficult for grassroots personnel to master
	A2 The model maintenance cost is high and the grassroots cannot bear it
	A3 Existing software does not match traditional craftsmanship
	A4 Disadvantages in mountain networks and infrastructure
B2 Technology application potential	A5 BIM can accurately record structure and technical processes
	A6 Improve construction efficiency and cost control
	A7 Realize long-term monitoring and risk warning
B3 Risk of lack of cultural connotation	A8 Young inheritors have severe fault
	A9 Cultural connotations are fragmented and difficult to spread
	A10 Skill-related customs and formulas are on the verge of loss
B4 Cultural information integration	A11 Information such as rituals, formulas and other information must be extracted and integrated
	A12 Avoid "focusing on form over spirit", cultural experts need to be involved
	A13 Inheritors are the core source of cultural information
B5 Cross-departmental collaboration dilemma	A14 Lack of stable and effective cross-departmental coordination mechanism
	A15 The responsibilities and goals of each department are inconsistent
	A16 Inconsistent technical standards lead to difficulties in collaboration

	A17 There are barriers to data sharing
B6 Funds and Talent Resources	A18 Lack of sustainability of capital investment
	A19 Compound professional talents are extremely scarce
	A20 Insufficient local supporting funds, projects are prone to delay
B7 Audience demand orientation	A21 Content production needs to distinguish different audience needs
	A22 Public-oriented content should be intuitive and interesting
	A23 Content for professional groups needs to be in-depth and practical
B8 Effectiveness Assessment Dimension	A24 The core of the evaluation is the actual utility rather than the number of users
	A25 Pay attention to knowledge acquisition rate and deepen cultural understanding
	A26 Pay attention to inheritance intention and participation in behavior transformation
	A27 Project reuse rate is an important project value indicator

Selective coding

Selective coding continues axial coding at a higher level of abstraction. The purpose of this step is to identify core categories around which other proposed categories can be merged and integrated. This article uses selective coding to obtain four core main categories, namely technological adaptability factors, cultural authenticity factors, resource synergy factors, and communication effectiveness factors.

Table 2: Selective encoding

Coding	Main category	Corresponding category	Category connotation
C1	Technical adaptability factors	B1 Technology flooring barriers	Technical adaptability factors describe the matching and contradiction between its technical capabilities and complex real environments when applying cutting-edge digital technologies (such as BIM, three-dimensional scanning) to Dong building protection. On the one hand, it contains huge potential: BIM and other technologies can systematically and accurately record building structures, create technical processes and intangible cultural information, solve the problems of traditional drawings and photos "focusing on form over spirit" and information separation, and improve repair efficiency, reduce costs, and achieve long-term monitoring and early warning. But on the other hand, it also faces severe obstacles to implementation: the existing software does not match the traditional technology, and lacks templates for Dong ethnic wood structures; the software operation of grassroots personnel is difficult, the subsequent model maintenance costs are high and the grassroots cannot afford it; at the same time, poor infrastructure such as networks and power in mountainous areas lead to difficulties in data collection and transmission, and it is difficult to implement advanced equipment in remote villages. This creates a significant tension between the advanced nature of the technology and the local conditions.
		B2 Technology application potential	
C2	Cultural authenticity factor	B3 Risk of lack of cultural connotation	The cultural authenticity factor is related to whether the spiritual core and non-technical knowledge of cultural heritage can be truly and completely preserved and conveyed in the process of digitalization. The core contradiction is that the profound cultural connotation faces serious risks of inheritance and extraction: young inheritors are broken, and rituals, formulas, and customs related to skills are on the verge of being lost; most old craftsmen "can do and not say", resulting in fragmented cultural logic and difficult to spread. Therefore, digital
		B4 Cultural information integration	

			work is far more than recording geometric forms, but also requires systematic extraction and integration of the "god" parts, such as creation rituals, craftsman experience, ecological wisdom, site selection logic, etc., and transform them into parameters or comments that can be integrated into the model. The key to achieving this goal is to establish the core subject position of the inheritor, so that he, as the "source of information" and "cultural authority", deeply participates in the entire process from modeling to dissemination, so as to ensure the cultural authenticity and accuracy of the digital model and avoid the emergence of a digital empty shell that emphasizes form and neglects the spirit.
C3	Resource synergy factors	B5 Cross-departmental collaboration dilemma B6 Funds and Talent Resources	Resource synergy factors reveal the resource allocation and collaboration mechanisms that promote interdisciplinary and cross-departmental Dong building digital projects rely on. Project success is highly dependent on continuous and stable capital investment and compound talents who understand technology, architecture and culture. Both are indispensable. However, in reality, we often face the dilemma of insufficient local supporting funds and extremely scarce talents. The deeper challenge lies in the failure of cross-departmental collaboration: the lack of a stable and long-term coordination mechanism, the goals and demands of various departments (cultural relics, housing and construction, cultural tourism, universities, etc.) have different goals and demands (protection, safety, innovation, profitability), and different technical standards, resulting in unclear responsibilities, high communication costs, and barriers to data sharing. Key resources such as funds, talents, and data cannot be effectively coordinated and flowed among various departments, creating a situation where it is difficult to concentrate, which seriously restricts the project's promotion efficiency and final results.
C4	Factors of transmission effectiveness	B7 Audience demand orientation B8 Effectiveness Assessment Dimension	The communication effectiveness factor focuses on how digital achievements go beyond the "database island" and are truly applied and realize their social and economic value. Its connotation emphasizes that the key to measuring success is not the superficial number of users or downloads, but the actual auxiliary effect of protection, inheritance, education, culture and tourism. To achieve effective communication, content production must be guided by audience needs: it must be in-depth and practical for professional students, intuitive and interesting for the public, and accurate for inheritors and protection departments. Therefore, promoting the "out of the database" of results requires proactively connecting with the education and cultural tourism industries, and transforming data into school-based courses, practical training systems, AR guides, cultural and creative products, etc., so that knowledge can be disseminated and economic benefits can be created. Ultimately, the evaluation of the effect of communication should focus on substantive indicators such as "knowledge acquisition rate", "cultural understanding deepening rate", "inheritance intention conversion rate" and "project reuse

			rate", to ensure that digital investment can truly empower people and activate the vitality of the heritage.
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Quantitative data analysis results

This survey is based on 310 valid questionnaires and focuses on the key factors in the inheritance and dissemination of the Dong architectural intangible cultural heritage. The study conducted analysis from four dimensions: demographic characteristics, cultural exposure, digital technology awareness and communication channel preference. Descriptive statistical results show (see Table 1) that respondents have a positive and open attitude towards the application of digital technologies such as BIM/VR (M=4.12, SD=0.68), and short videos (M=4.35, SD=0.72) and immersive experiences (M=4.28, SD=0.75) have become the most concerned forms of communication. It is worth noting that skill loss (M=4.41, SD=0.63) and backward communication methods (M=4.08, SD=0.71) are generally regarded as the main obstacles to inheritance, and young groups show a significant preference for interactive game-based communication methods (M=4.52, SD=0.58). These data provide a reliable statistical basis for understanding the public's current understanding of the Dong's wooden construction skills.

Table 3: Summary of descriptive statistics of main study variables (N=310)

Dimensions	Measured variables	Mean (M)	Sstandard Deviation (SD)	Measurement scale
Digital technology awareness	BIM/VR technology acceptance	4.12	0.68	5 point scale
Communication channel preference	Short video platform	4.35	0.72	5 point scale
Communication channel preference	Immersive experience	4.28	0.75	5 point scale
Awareness of inheritance disorders	Skill loss crisis	4.41	0.63	5 point scale
Awareness of inheritance disorders	Communication methods are backward	4.08	0.71	5 point scale
special group preferences	Youth interactive gaming tendencies	4.52	0.58	5 point scale

Note: All measurements are on a 5-point Likert scale (1=strongly disagree, 5=strongly agree)

APP functional requirements show diversified characteristics

Research data on the building protection APP functions expected by users show that their needs show significant diversification and gradient characteristics. The specific statistical results are as follows:

Table 4: Functional requirements preference analysis of building protection APP (N=310)

Function module	Preference ratio	M	SD	Demand intensity level
Craftsman skills teaching video	92.6%	4.63	.62	core needs
Community forums and exchanges	82.9%	4.41	.75	strong demand
Interactive virtual construction tasks	58.7%	3.72	.91	medium demand
360° panoramic tour	36.8%	3.08	.05	Basic needs

Note: The preference ratio is based on the proportion of respondents who selected "need" and "very need" for this feature; the mean and standard deviation are calculated based on a 5-point Likert scale (1=not at all, 5=very need).

Users' expectations for the building protection APP are a comprehensive platform that integrates "systematic teaching, community interaction, gamification experience, and immersive display". The development strategy should follow the demand gradient, giving priority to consolidating the core knowledge inheritance and community communication functions, and then gradually expand the interaction and roaming functions to accurately meet the diverse and hierarchical needs of users.

Hypothesis testing based on structural equation model

In order to verify the theoretical model constructed in this study, we used AMOS software to analyze the collected 310 valid questionnaire data. First, the goodness of fit of the model was tested, and then path analysis was performed on the proposed research hypotheses.

Model goodness of fit test

The model fitting index shows that the χ^2/df value is 2.15, which is less than the strict standard of 3; the CFI and TLI values are 0.94 and 0.93 respectively, both greater than the excellent standard of 0.9; the RMSEA and SRMR values are 0.06 and 0.04 respectively, both less than the critical value of 0.08. All key fit indicators meet or exceed the recommended values, indicating that the structural equation model fits the questionnaire data well and can perform effective path analysis.

Table 5: Structural equation model goodness-of-fit index (N=310)

Fit index	Test result value	Judgment criteria	Model compliance
χ^2/df	2.15	< 3	excellent
CFI	0.94	> 0.9	excellent
TLI	0.93	> 0.9	excellent
RMSEA	0.06	< 0.08	good
SRMR	0.04	< 0.05	excellent

Path analysis and hypothesis testing

Based on the theoretical model, this study examined the path relationships between latent variables. To visually display the analysis results, detailed hypothesis testing results are listed.

Table 6: Model path coefficients and hypothesis testing results

Hypothetical Path	Relationship Direction	Standardized Path Coefficient(β)	Standard Deviation (S.E.)	Critical Ratio (C.R.)	Whether the hypothesis is true or not
H1: Technology empowerment → Inheritance intention	forward	0.32	0.07	4.571	established
H2: Cultural identity → Willingness to inherit	forward	0.41	0.06	6.833	established
H3: Policy support → Technical empowerment	forward	0.55	0.08	6.875	established
H4: Communication effectiveness → Inheritance intention	forward	0.28	0.05	5.600	established
H5: Resource synergy → cultural identity	forward	0.47	0.07	6.714	established

Note: means $p < 0.001$

The analysis results of structural equation modeling statistically verified the theoretical framework based on questionnaires and interviews. It not only confirms the existence of key factors (technology, culture, policy, resources, communication), but more importantly, accurately quantifies the causal network between them, providing a solid empirical basis for understanding the digital inheritance mechanism of Dong architectural intangible cultural heritage.

Specific comparison of response rate or popularity rate

Compare the difference in response rate or popularity rate through the collected data. Specifically, the public believes that the value of Dong wooden construction techniques (such as mortise and tenon structure) is mainly reflected in tourism and economic value, engineering and technical value, and historical research and archaeological value. The response rate and popularity rate of a total of three items are significantly higher. This survey clarified the core contradictions and solutions to the inheritance of Dong architecture - using online digital means to lower the cognitive threshold, building a solid inheritance foundation with craftsman cultivation and technical records, realizing a closed loop of value with the tourism economy, and ultimately promoting Dong architecture from "endangered protection" to "living inheritance."

Key factors in the inheritance and dissemination of digital Dong architectural intangible cultural heritage based on BIM

Digital expression mechanism of cultural semantic information

The semantic meaning of Dong architectural culture does not simply exist in the physical structure, but is manifested in narrative logic such as spatial order, pattern symbols, and collective memory. The concept of group sharing and ritual space can be clearly seen in the Dong village architecture in the Liuzhou area. For example, the Drum Tower represents unity, while the Wind and Rain Bridge symbolizes protection. But if these cultural connotations are recorded solely through images, they can easily be misunderstood or fractured. BIM digital modeling can embed the above cultural elements into model parameters through information attributes, semantic tags, etc., thereby realizing full information expression from structure to culture. Through the setting of cultural semantic nodes, carving textures, ceremonial spaces and symbolic meanings can be mapped to data attributes, so that the architectural model has the ability to identify cultural semantics, thereby making Dong architecture have the characteristics of readability, traceability and scalability, and providing in-depth data support for cultural reproduction.

Table 7: BIM parametric expression of the core cultural semantics of Dong architecture

Cultural Dimension	Typical Components	Core Cultural Semantics	BIM Parameterized Bearing Method	Digital Expression Output
Social Structure	Drum Tower	Even plane = unity and equality • Odd number of layers = order of heaven and earth	Geometric parameters: number of sides, number of layers Semantic rules: IF(Number of edges %2=0, "Compliance", "Error")	Automatic verification report of cultural regulations; semantic labeling of 3D models
Natural Ecology	Gua Zhu	The shape imitates the cedar tree = worship of the tree of life • The number of overhanging layers = the meaning of family reproduction	Modeling parameters: closing ratio, number of overhanging layers • Semantic tag: "Tree of Life Symbol - Family Prosperity"	Component cultural connotation query panel; cultural symbol annotation
Ecological Wisdom	Fire Material	Using local materials, cutting one kind of wood, roasting and antiseptic	Material properties: origin, durability Knowledge Notes: Sustainable recycling concept, traditional craft description	Ecological wisdom assessment report; material cultural value description
Ritual Life	Fire Pond	Sacred center of the family, orientation taboos, discussion functions	Spatial parameters: distance from center column, spatial orientation • Functional Notes: Ritual functions, usage taboos	Immersive roaming cultural commentary; spatial function analysis diagram

Parametric modeling path of wood construction technical knowledge

The traditional wooden architecture of the Dong ethnic group in Liuzhou is characterized by special mortise and tenon connections and beam-lifting structures. The craftsmanship logic is based on the inheritance of experience and proportions. In order to avoid the loss of such non-textual knowledge, BIM parametric modeling can turn traditional structural rules such as mortise and tenon joints, beam-column ratios and bracket levels into digital parameters, and use family library definitions and logical constraints to build an accurate restoration mechanism. Different from static three-dimensional models,

parametric modeling retains the characteristics of process logic while reconstructing the physical form, making the model "reconstructible" and "variable". The core of this approach is to build a structural knowledge system and translate traditional construction techniques into a computable data language, thereby providing continuous technical support for technique teaching, restoration simulation, and cultural dissemination.

Interactive construction elements of visual communication experience

The digital protection of intangible cultural heritage buildings is not only the recording of information but also the reconstruction of cultural communication experience. The Drum Tower and Wind and Rain Bridge among the Dong buildings in Liuzhou have both ritual and daily characteristics, and their value should be recognized by the public through multi-sensory experience. After the BIM model is integrated with VR/AR, it can realize structural level disassembly, space roaming and material interaction, allowing users to perceive the craft logic and cultural context of the building in the virtual environment. The key elements of interactive construction mainly include three levels: spatial realism, intuitive operation and cultural narrative: using visual rendering to restore the texture of wood, using motion feedback to enhance the sense of presence, and using embedded voice explanations and story scripts to recreate cultural situations. This interactive system can make Dong architecture "seen", "experienced" and "inherited".

Digital sharing system of inheritance subject collaboration

The protection and inheritance of Dong architecture cannot be separated from the cooperation and participation of craftsmen, scholars, management agencies, community residents and other parties. The Dong villages in Liuzhou area are characterized by wide distribution and obvious structural differences. The traditional protection model has problems such as information fragmentation and low efficiency. The digital sharing system with BIM as the core can integrate data and knowledge from multiple parties to achieve the goals of model co-construction, repair, co-management and cultural co-transmission. The system establishes interfaces with different permissions based on the cloud database, enabling craftsmen to upload component data, researchers to analyze structures, and the public to participate in cultural experiences. Through standardized data formats and version tracking mechanisms, accurate information circulation and dynamic updates are ensured, and a "data symbiosis-knowledge co-creation, cultural co-protection" inheritance network is formed to advance the intangible cultural heritage protection of Dong architecture to the stage of sustainable digital governance.

Integrated model construction strategy for traditional wood structure protection and visualization based on BIM technology

Construct a BIM information model system driven by cultural semantics

The information model system powered by cultural semantics is the basic support for the transition of Dong architecture from physical space to digital space. The core purpose is to make the BIM model not only a tool for reproducing the architectural structure but also a medium for carrying cultural semantics and historical information, so as to achieve the "cultural readability" of digital architecture. When constructing the model, the Dong architectural cultural logic was first used as an information framework to classify and analyze the cultural meanings of architectural community spaces, drum floor levels, beam-column ratios, mortise-and-tenon joints and decorative patterns, and an information semantic mapping table was constructed based on cultural functions and structural attributes. Subsequently, in the BIM environment, the family library (Family Library) is used as the core to define component families with cultural characteristics: for example, the "Tianzhu Zhu", "Main Beam" and "Dougong" components are given load-bearing, ritual and aesthetic semantic attributes to express their structural and cultural inner logic through parametric relationships. Each component embedded in the model not only contains geometric and physical information, but also contains cultural semantic nodes such as "bridge - unity" and "beam frame - refuge" cultural mapping words. In this way, the model constitutes a multidimensional information system in which the semantic layer and the structural layer are bundled with each other. Then information coding rules are used to build a cultural index system, so that different building types, component categories and pattern forms can achieve the purpose of rapid retrieval and cultural tracing. The model system finally realizes the cultural perception function of BIM in a semantic-driven manner, so that the model can not only provide services for structural repair and academic research, but also provide services for subsequent virtual display. The cultural narrative function carried by educational dissemination builds a self-explanatory intelligent information base for the digital protection of Dong buildings.

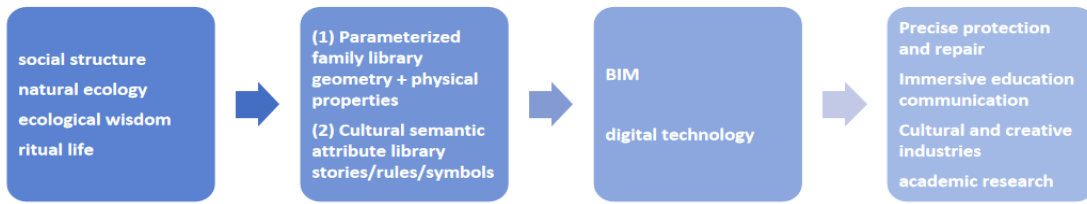


Figure 1: Visual protection model diagram of Dong buildings

Deconstruction and encoding of Dong architectural culture semantic system

In order to realize the digital embedding of cultural semantics, it is first necessary to systematically deconstruct and encode the deep cultural logic contained in the Dong architectural system. This part will establish a cultural semantic classification and coding system that can be recognized and processed by the BIM system from the three dimensions of space, components, and technology.

The spatial layout of Dong buildings is not a random geometric combination, but a symbolic system that carries social structure, cosmology and national memory. The deconstruction of its cultural logic is shown in the following table

Table 8: Deconstruction of cultural logic of Dong architectural spatial order

Spatial hierarchy	Typical examples	Cultural logic and symbolic meaning	BIM coding
Settlement level	Village layout	"Mountain on the back and water on the face": imitating natural acupuncture points and embodying the ecological view of harmony between man and nature. "Drum Tower - Stage - Altar" Central Square: As the spiritual, political and cultural center, it is the materialization of the social structure.	Spatial_Type: "Settlement" Cultural_Logic: "Harmony_Between_Heaven_and_Human" Social_Structure: "Communal_Center"
Construction group	Residential buildings surrounding the Drum Tower	The radial or clustered layout symbolizes the inward cohesion with the family or clan as the core.	Spatial_Relation: "Cluster_Around_Core"
Single building	Drum Tower	Number of layers: Must be an odd number, related to concepts such as the three realms of "heaven, earth, and man" or the nine heavens in the Dong's cosmology, representing holiness and order. Plane: mostly even-numbered sides (such as four corners, hexagons, and octagons), symbolizing unity, equality and stability.	Building_Type: "Drum_Tower" Floor_Count: 7 (Must_Be_Odd) Plan_Shape: "Octagon" (Must_Be_Even) Symbolism: "Sacred_Order; Unity"
Interior space	Fire pit location	Located in the center of the house or near the center pillar, it is the spiritual core of the home and symbolizes warmth, togetherness and heritage. Its orientation and distance from the center column have specific cultural taboos.	Space_Function: "Fireplace_Hearth" Cultural_Significance: "Family_Spiritual_Core" Taboo: "Cannot_Stride_Over"

Every key component of Dong ethnic architecture is a cultural symbol endowed with specific meanings, and its form directly originates from nature worship and life philosophy (as described in the following table).

Table 9: Symbolic Deconstruction of the Form of Dong Ethnic Architectural Components

Component category	Typical examples	Symbolic interpretation and cultural metaphor	BIM
Structural component	Gua Zhu	Its form of emerging layer by layer and gradually tapering from top to bottom mimics the growth of a fir tree and is a direct manifestation of the "tree of life worship", symbolizing vitality, growth and the prosperity of the family.	Component_Type: "Bracket_Set" Form_Metaphor: "Tree_of_Life" Symbolic_Meaning: "Growth; Prosperity"
	Chuanfang	Crisscrossing and connecting the entire wooden framework, it symbolizes the connection and collaboration among family members and is the materialization of social network relationships.	Component_Type: "Linking_Beam" Social_Metaphor: "Family_Connection"
Decorative components	Eave corner decoration	They are often made in the shapes of birds, fish, etc. Birds symbolize the souls of ancestors (totem remnants), and fish symbolize having many children and good fortune. Both are reflections of nature worship.	Component_Type: "Eave_Ornament" Form_Metaphor: "Bird_Ancessor; Fish_Fertility"
	stone carving of column bases	There are often patterns such as lotus flowers and gourds. The lotus symbolizes purity and transcendence, while the gourd in mythology represents protection and reproduction.	Component_Type: "Column_Base" Pattern_Symbolism: "Lotus_Purity; Gourd_Protection"

Through the above systematic deconstruction and coding, we have constructed a complete "cultural gene bank" for Dong ethnic architecture. This gene bank will be used as a standardized data dictionary and input into the BIM environment, thus making the subsequent parametric modeling no longer a simple geometric operation, but a profound process of cultural semantic injection.

Semantic Information Embedding Method and Technical Implementation Based on BIM

After deconstructing and encoding the cultural semantic system, it is necessary to effectively embed these structured cultural information into the BIM model. The following is a complete demonstration of the semantic information embedding process from basic components to the complete model

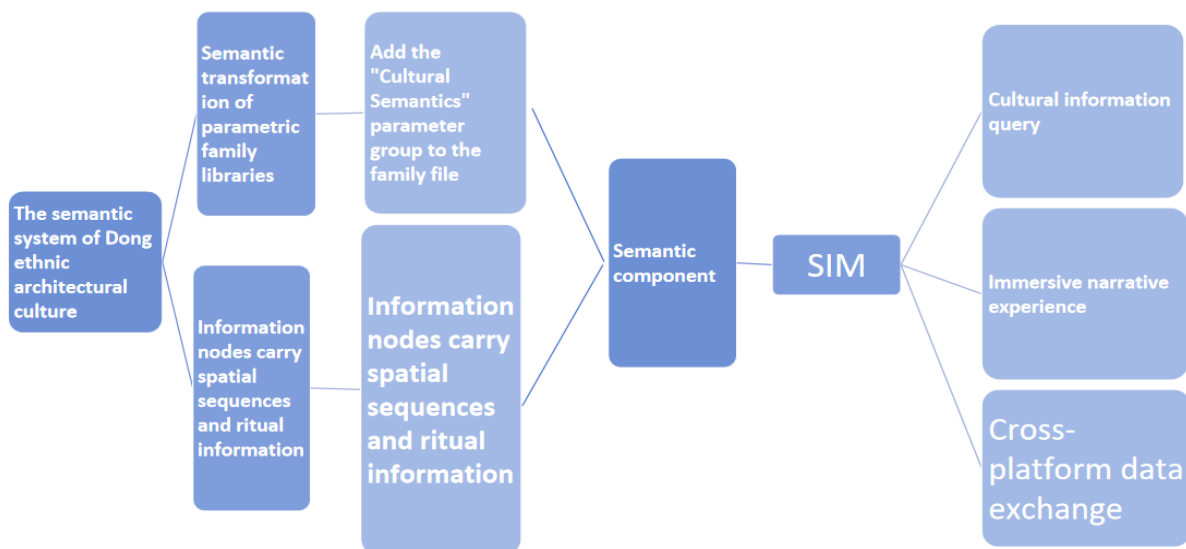


Figure 2: Semantic Information Embedding process

Empirical Research on the Model of Promoting Factors for Digital Inheritance Based on Hybrid Methods

This study adopts a hybrid method combining qualitative analysis and quantitative verification to systematically explore the promoting mechanism of digital inheritance of Dong ethnic architecture. Through grounded theory analysis of expert interviews, five core factors were extracted. Based on 310 valid questionnaire data, the action paths of each factor were verified through the structural equation model as follows:

The core role of cultural authenticity: It has the most significant impact on the effectiveness of communication ($\beta=0.43$), emphasizing the importance of maintaining the authenticity of skills and cultural connotations.

The fundamental support for technological adaptability: It directly affects the effectiveness of communication ($\beta=0.31$), reflecting the fundamental role of technological tools in digital inheritance.

Systematic support of policy resources: Policy support generates significant indirect effects through resource synergy, with a path coefficient reaching 0.58.

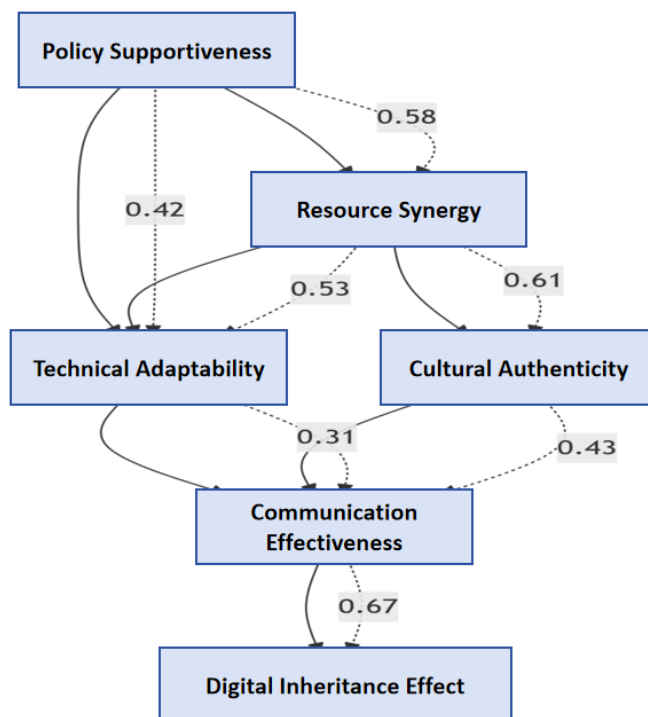


Figure 3: Path diagram of the structural equation model established in the research, which shows the causal relationship and intensity of action among various influencing factors

Establishing a parametric restoration and dynamic analysis mechanism for wooden structures

Constructing a parametric restoration and dynamic analysis mechanism for wooden structures is a key link in the systematic inheritance of Dong construction technology knowledge and the scientific evaluation of structural performance. Dong traditional architecture uses mortise and tenon joints and lifting beams as the centerpiece. The construction process includes rigorous mechanical logic and proportional aesthetics. The construction of this mechanism is based on BIM parametric modeling capabilities, realizing the transformation of traditional empirical construction techniques into calculable and verifiable digital language. In the preliminary stage of modeling, we digitally scanned and geometrically reconstructed traditional components, and created a parameter library of key components such as beams, columns, purlins, buckets, and arches. By adjusting variable parameters such as component length, connection angle, node spacing, etc., the purpose of automated assembly and proportion adjustment is achieved. Secondly, during the structural analysis stage, the model was imported into the finite element analysis module to conduct static and dynamic two-dimensional tests to simulate the stress distribution and deformation of the building when factors such as wind load, earthquake, and humidity change. Especially at the mortise and tenon joints, set the friction coefficient, shear strength and wood elastic modulus to dynamically visualize the mechanical response. Finally, the

structural health index and repair recommendation table are formed by comparing the calculation results in the performance evaluation stage with historical measured data, thereby providing a quantitative basis for subsequent protection intervention work. The practical innovation of this mechanism is to realize the digital linkage of the three aspects of "technique-structure-expression" of Dong architecture, which not only retains the traditional craft logic but also promotes the scientific management level of building structure safety, so that Dong wooden buildings have the dynamic vitality of "restorable, verifiable and repairable" in the digital space.

Build an immersive experience-oriented visual display system

The immersive experience-oriented visual display system is a key strategy for expanding Dong architectural BIM and digital models from the academic research level to the cultural communication level. The core route of this system is "reconstruction of digital space - design of interactive experience - integration of cultural narrative". With the help of visualization technology, the public can "walk into" Dong architecture in a virtual environment and understand the structure and cultural spirit of Dong architecture. When building the system, the BIM and digital model data were first lightweighted to achieve smooth loading of high-precision architectural models on the VR/AR platform. Then, with the assistance of the virtual engine, a realistic environmental scene is generated, using light and shadow rendering, material reproduction and sound effect synthesis to restore the wood texture, light flow and environmental soundscape, etc., to enhance the visual and auditory immersion. In the interactive design process, the system sets the operation response logic of each building component. For example, clicking on a mortise and tenon node can trigger an automatic disassembly animation, simultaneously displaying its structural principles and cultural implications. Users can also choose the navigation mode to enter the cultural interpretation space at each building level to achieve an experience that gradually moves from structural viewing to cultural understanding. In order to enhance the cultural narrative function, audio explanations, text annotations and virtual character guidance are systematically elaborated, so that Dong building construction stories, festival rituals and life scenes are dynamically reproduced in the virtual space. The display system not only serves public education and cultural display, but also provides researchers with a platform for structural demonstration and teaching experiments. Through the deep integration of BIM and digital data, virtual simulation and cultural narrative, the system enables the digital protection of traditional buildings to move from "information visualization" to "cognition of experience", enabling the Dong architectural culture to achieve real, perceptible and sustainable regeneration and communication in the digital era.

Establish a monitoring and management platform supported by digital archives

The establishment of a monitoring and management platform supported by digital archives is a key strategy for Dong architectural protection to move from "static recording" to "dynamic monitoring". The platform uses the BIM information model as the core data container to integrate sensor monitoring, data collection, cloud analysis and visual decision-making, and establish a sustainable digital supervision system. The system construction is first based on the fusion of multi-source information, and unified coordinate alignment and format standardization of data such as 3D laser scanning, drone oblique photography, material detection, and structural surveying to form an accurate digital archive of the building. Secondly, multi-functional sensors are deployed at key nodes of the building (such as load-bearing column bases, bucket arch nodes, roof beams, etc.) to monitor humidity, temperature, vibration and stress changes in real time, and realize automatic data synchronization with the BIM model through the Internet of Things module. Monitoring points embedded in the model can dynamically update attribute information and visually display the health status of the building in a three-dimensional environment. In the event of abnormalities in monitoring data, the system activates an early warning mechanism to automatically generate a risk report and associate it with historical maintenance records. The platform's cloud architecture supports multi-agent collaboration. Researchers can analyze the structure online, management departments can develop repair plans, and cultural institutions can extract models for demonstration and education. In order to ensure the long-term availability of data, the platform uses time stamps and version tracking mechanisms to completely record the transformation process of the building and trace the protection decisions. Through this mechanism, the protection of Dong buildings has been transformed from "post-event repair" to "real-time diagnosis", forming a "data collection-risk identification-intelligent decision-making-restoration implementation" cycle system, allowing cultural heritage monitoring and information management to achieve a standardized, intelligent, and sustainable deep integration.

Develop virtual media communication prototypes supported by BIM and digital models

Based on the BIM and digital semantic models and visual display results built in the early stage, the development of virtual media communication prototypes is a key link in the process of promoting the social transformation of the digital achievements of Dong architectural creations. The prototype uses BIM and digital models as the data core, combines virtual reality and multimedia technology, and builds a digital application system that integrates cultural dissemination, knowledge education, and interactive experience. The system design phase adopted the research and development concept of "lightweight modeling - multi-terminal adaptation - interactive narrative" to compress complex BIM data into a model format that can be operated smoothly on mobile terminals to achieve cross-platform compatibility. The functional design is divided into three major modules: the first is the structural exploration module, where users can freely browse three-dimensional models of typical buildings such as the Drum Tower and Fengyu Bridge, and disassemble components through touch operations to intuitively understand the logic of mortise and tenon craftsmanship; the second is the cultural navigation module, which combines voice explanations and text prompts to display the historical background of the building, decorative meanings and social functions; the third is the interactive learning module, where users can use a task-driven form to complete virtual assembly and cultural Q&A activities, using gamification methods to enhance memory and cognition. After the system was developed, a functional and experiential two-dimensional evaluation system was introduced to measure the prototype with visual immersion, interactive response speed, learning effectiveness and cultural identity as dimensions to ensure both communication effects and educational value. The evaluation results are analyzed through user feedback and system logs to form an iteratively optimized report to continuously enhance interactive performance and the depth of cultural content. The construction of this virtual media APP prototype has enabled BIM and digital technology to make breakthroughs in academic and engineering fields and transform into cultural communication tools. It has expanded the Dong architecture from "data protection" to "public experience" across borders, and provided a concrete and sustainable communication medium for the digital inheritance of national architecture.

Build a public participation-oriented cultural and educational communication mechanism

Constructing a public participation-oriented cultural and educational communication mechanism is a key strategy to ensure the true implementation of the digital protection system of Dong buildings and the formation of social influence. This mechanism follows the core concept of "co-construction and sharing, and promoting dissemination through teaching" and builds a multi-level interactive framework that closely links academic research, public cognition and cultural identity. First of all, from the perspective of communication, with the help of the virtual media APP and online and offline digital museum platforms mentioned above, a freely accessible three-dimensional resource library of Dong architecture is provided to the public, allowing people to independently explore the structure and cultural meaning of the building in an intuitive scene; at the same time, through interactive functions, users are encouraged to upload study notes, provide protection suggestions and other content, and form a cultural archive co-created by users. Secondly, in terms of education, the construction of digital teaching resource packages based on BIM and digital models promotes their introduction into courses such as university architecture, cultural heritage protection, and aesthetic education in primary and secondary schools, providing systematic teaching and intuitive understanding of traditional architectural knowledge. Teachers can use models to assist in demonstrating mortise and tenon connection methods, proportional construction rules, spatial organization logic, etc., so that abstract knowledge can be displayed in a three-dimensional form to enhance students' learning experience. Furthermore, from the perspective of social participation, it combines community and intangible cultural heritage research, and uses interactive projects such as virtual construction competitions, digital restoration experiences, and cultural story interpretations to create emotional resonance and awareness of protection among the public. Construct a feedback evaluation system on the operation of the mechanism to quantitatively analyze the breadth of communication, educational impact and participation, and continuously optimize the communication strategy.

Conclusions

Based on BIM and digital technology, we conduct visual protection and research on Dong buildings, and systematically integrate cultural semantics into digital models. The semantic-driven modeling system and visual communication model constructed through research realize the reproduction and inheritance of the skills, form and spirit of Dong architecture in the digital space. This model not only provides innovative ideas for the full-frame digital protection of national architecture, but also provides scalable technical reference for visual management and public communication of regional

traditional building groups. In the future, virtual reality and artificial intelligence can be further combined to intelligently present and interactively inherit the Dong architectural digital heritage.

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