

A STUDY ON FACTORS AFFECTING THE REPAIR AND MAINTENANCE OF ANCIENT BUILDINGS IN COLD REGIONS OF CHINA - TAKING NORTHEAST CHINA AS AN



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Abstract

With the continuous evolution of the city, the integration and dialogue between old and new buildings have brought wonderful experiences to the public. China's ancient buildings have witnessed history and have both high appreciation value and construction reference. However, as time goes by, a large number of ancient buildings are in a bad state due to the influence of various factors such as their characteristics, region, and climate environment. China's cold regions are extensive, with long and cold winters, which has caused great damage to the materials in the wooden structure system of ancient buildings and the interaction between them and further affected the repair and maintenance of ancient buildings. This article combines relevant literature and cases, specifically analyzes the impact of the cold climate in Northeast China on ancient building materials, extracts key dimensions to construct a factor framework, determines key factors, summarizes relevant experiences, and proposes scientific, practical, and normative systematic strategies to improve the durability and safety of buildings in cold regions from the root, ensuring that they can remain stable and reliable even in extremely cold weather.

Keywords: Artistic innovation, Ancient buildings, Repair & Maintenance, Climate

Introduction

Northeast China is located in the north and east of China. It has a severe cold climate, long and cold winters, often accompanied by snow and freezing, and precipitation concentrated in the summer. This seasonal climate change has a significant impact on building materials and structures, which can easily cause the expansion and contraction of ancient building materials, resulting in cracks and falling off (Qin H.L, 2013). Northeast China has many historical and cultural heritages such as the Shenyang Imperial Palace and the Changbai Mountain Ancient Buildings, which are of great value. However, the severe cold climate has exacerbated the damage to ancient buildings, making repair difficult. During maintenance, it is necessary to ensure the integrity of traditional craftsmanship and consider the adaptability of modern technology. At the same time, the shortage of funds and professionals is also a problem. How to effectively protect and repair ancient buildings under severe cold conditions has become an important issue.

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Research Purposes

Ancient buildings in the cold regions of Northeast China are valuable witnesses of historical and cultural heritage and are of extraordinary value. However, at present, ancient buildings in Northeast China are facing problems such as structural and appearance damage and threats to the life of materials. The current status of protection and repair varies, and there is a lack of systematic research based on uniqueness. Starting from the characteristics of cold-region building protection, this paper explores the key factors in the repair and maintenance of ancient buildings and explains the protection and restoration strategies under special regional conditions. It aims to provide a reference for the protection of ancient buildings in Northeast China, promote economic development and tourism, and achieve a win-win situation for the economy and culture.

The severe cold and snowy winters in Northeast China have caused a lot of damage to ancient buildings. This article reviews the literature on the repair and maintenance of ancient buildings and extracts experience from cases. Through qualitative and quantitative research, key dimensions are established to improve the framework of ancient building repair and maintenance in cold climates. In-depth research on the influencing mechanism and countermeasures is conducted to improve the durability and safety of buildings in cold regions.

Literature Review

Theory of Repair and Maintenance of Ancient Buildings

Common types of damage to ancient buildings and their causes: caused by differences in drying rates inside and outside the wood, long-term loads, wood aging, and changes in temperature and humidity; Decay: Under poor ventilation conditions, mold spores on the surface multiply rapidly, causing the wood to mold and mildew; Deformation: The bearing capacity of the wood decreases due to aging or the load on the structure is too large and exceeds the range allowed by the specification; Tenon pulling: Long-term load action and the shrinkage of the wood itself cause the mortise and tenon joints to loosen; (Huang T.Q., 1998) Defect phenomenon: The material of the wood changes due to external influences such as structural abnormalities or adverse environmental factors; Biological diseases: Mainly refers to the corrosion of wood by insects such as termites, powder beetles and wood-boring wasps.

Principles and methods of repair and maintenance of ancient buildings: The protection and restoration of ancient buildings involves a wide range of fields, including the protection of building materials, the stability of the structure, the restoration of decoration, etc. It is mainly based on the five principles of raw material priority, moderate restoration, comprehensive protection of sustainable development, and reasonable renewal of the ancient for the present. In the process of protection and restoration, supporting facilities should be repaired and rebuilt to maintain the overall style and historical atmosphere of the ancient buildings. (Lin N., Zhang X.W, Liu J., 2020)

In the protection and repair of ancient buildings in China, the following five situations are usually included: daily maintenance (i.e. routine maintenance), protection and reinforcement, current renovation, key restoration, and reconstruction on the original site. The purpose is to formulate specific protection measures according to the degree of damage to the building and the intensity of the repair. However, in actual operation, the main methods for the wooden structure of ancient buildings are to connect the column roots, wrap the column roots, replace the columns and auxiliary columns, replace the rafters, install the large wood, and prevent corrosion. (Qin H.L, 2015) In addition, when dealing with the artistic components with carvings in ancient buildings and the attached artworks, random repairs should be avoided as much as possible to maintain their original style and artistic value.

Special problems in the cold climate of Northeast China: In the cold climate,

materials such as stone and brick masonry are easily affected by freeze-thaw cycles, resulting in cracks and peeling. Thermal expansion and contraction also affect the structural integrity. There are many winds and snows in the Northeast in winter, and the accumulation of snow can easily cause the collapse of ancient buildings and wear and tear on the appearance. After the snow melts, water infiltration causes freeze-thaw erosion, accelerating the aging and weathering of building materials. High humidity all year round accelerates the corrosion of metal cultural relics and the growth of mold. Frost heave of the foundation is the main factor in the stability and integrity of ancient buildings, which can easily lead to serious situations such as sinking, tilting, and structural imbalance of ancient buildings.

Research Result

Research Design

Research Method: This article uses qualitative research to explore the key factors in the repair & maintenance of ancient buildings in Northeast China. This article designed a total of 17 questions and distributed them through the online questionnaire star. 631 sets of valid questionnaires were collected. The target group of this survey is professionals and related practitioners in the field of ancient building protection, including construction engineers, historical building protection experts, archaeologists, building materials researchers, and staff of relevant government departments. These groups have a deep understanding of ancient building protection and can provide valuable professional opinions and feedback.

Preliminary Analysis: The literature review reveals the impact of cold climate on ancient buildings, and the key dimensions are extracted through coding and classification.

In-depth Interviews: Semi-structured interviews were conducted with experts in architecture, ancient building protection, and meteorology, focusing on the impact of cold climate, adaptability of repair methods, and improvement strategies.

Results: The content analysis constructed a comprehensive factor framework, revealing the key factors in the repair and maintenance of ancient buildings in cold climates.

Literature Research

Table 1 Document coding results

Dimensions	Specific factors	Content
Climatic conditions	Effects of low temperature	Low temperature causes embrittlement of building materials and cracks caused by shrinkage and expansion.
	Freeze-thaw cycles	Damage to building structures caused by freeze-thaw cycles.
	Snow load	The pressure of snow on the roof and other parts of the structure.
	Humidity changes	Changes in humidity cause wood to decay and stone to weather.
Material properties	wood	Durability, corrosion, and insect pest issues of wooden structures.
	Brickwork	Weathering, spalling, and freeze-thaw damage to masonry materials.
	Protective coating	Effectiveness of fire-retardant coatings and anti-corrosion treatments.
structure type	Roof structure	The roof design's ability to handle snow and rain.
	Walls and foundations	Stability and durability of walls and foundations in cold climates.
	Connecting parts	Stability and protection measures of mortise and tenon structures.
Management and	Daily maintenance	The frequency and methods of routine inspections and minor repairs.

maintenance	Fire prevention measures	Application of fire protection systems and fire-retardant coatings.
	Technology and equipment	Application of modern technology in maintenance, such as temperature and humidity control systems and monitoring equipment.
environmental factor	Natural Environment	The direct impact of natural factors such as wind, rain, and snow on buildings.
	Human Factors	Damage to ancient buildings caused by human activities, such as urban development.

Expert interview

Interview outline design

This interview uses a semi-structured approach to explore the specific impact of the cold climate in Northeast China on the materials, structural forms, and management and maintenance of ancient buildings, evaluate the adaptability of current repair methods, and seek effective improvement strategies. The specific interview outline is shown in Table 2.

Table 2 Expert Interview Outline

Dimensions	Questions
Climatic conditions	What do you think are the main impacts of low temperatures, freeze-thaw cycles, snow loads, and humidity changes on the materials and structures of historic buildings? What measures have you taken to address the impact of these climatic conditions during the actual renovation process?
Material properties	What types of damage are common to wood, masonry, and protective coatings in cold climates? What anti-corrosion, insect control, and restoration techniques did you use during your renovation to address these issues?
structure type	What are some common problems with roof structures, wall foundations, and mortise and tenon joints in cold climates? When renovating these structures, what design and technical methods did you use to enhance their stability?
Management and maintenance	How important do you think routine maintenance and fire prevention measures are in the preservation of ancient buildings? In practical applications, how effective are modern technologies such as temperature and humidity control systems and monitoring equipment in maintenance?
Material properties	In what ways do natural environments (wind, rain, snow, etc.) and human activities (such as tourism and urban development) damage ancient buildings? What measures do you think are most effective in reducing the impact of these factors on ancient buildings?

Implementation and collection of interviews

Three experts (ancient architecture, architecture, and climatology) shared their views on the restoration and protection of ancient buildings in Northeast China, covering five aspects: climate, materials, structure, maintenance, and environmental factors. The interview lasted 3 hours and was transcribed into more than 30,000 words. Using NVivo11PLUS software, through three-level coding analysis, 43 third-level codes, 15 second-level codes, and 5 first-level codes were identified, which effectively reflected the research theme.

Table 3 Interview information coding results

Dimension/Open code	Specific Factors/ Axis Coding	Content/Selection Encoding	Original interview transcript
Climatic conditions	Effects of low temperature	The catalysis of low temperature on building materials and the cracks caused by shrinkage and	The winter in Northeast China is cold very much, and this low temperature will cause changes in the physical properties of building materials, especially wood and stone.

		expansion	
		Changes in material physical properties	The issue of building sealing is particularly important in cold climates. Low temperatures can cause sealing materials to harden or even crack, affecting their sealing performance.
		Building sealing	Low temperatures generally make materials more fragile and prone to cracking
	Freeze-thaw cycles	Damage to building structures caused by freeze-thaw cycles, especially the impact on foundations and walls	During the freeze-thaw cycle, the volume of water expands when it freezes inside the material and shrinks when it melts. This periodic volume change will generate stress inside the material. Over time, it will cause more microcracks in the material, which will then develop into visible cracks, or even peeling and breaking of the material.
		Material damage	In addition, freeze-thaw cycles can affect the stability of foundations, especially those that are not deep below the permafrost layer, which are prone to movement or deformation when the permafrost expands.
Material properties	wood	Durability, corrosion, and insect pest issues of wooden structures	Wood pests refer primarily to damage caused by various wood pests such as termites, whiteflies, and wood borers, which can penetrate the surface of the wood, get inside, feed on the wood, and dig tunnels and burrows in it, destroying the structural integrity of the wood.
		Pest Problems	If the moisture content in wood is too high for a long time, it will cause the wood to rot.
		Corrosive	Natural or added chemicals in wood (such as preservatives and pigments) may react chemically in cold and wet environments, causing its durability to decrease.
	Brickwork	Weathering, spalling, and freeze-thaw damage of masonry materials	When water freezes, it expands. When it reaches a certain level, the expansion force is enough to expand the micro-cracks inside the material, causing the surface material to peel off.
		Flaking	
structure type	Roof structure	The roof design's ability to handle snow and rain	Roofing designs must take into account local climate characteristics, such as temperature extremes, wind speed, and snowfall.
		Roof waterproofing and insulation	Waterproofing is a vital part of roof design, especially in cold regions. Insulation is another key factor. Good insulation not only reduces heat loss but also reduces heating costs.
	Walls and foundations	Wall and foundation stability and durability in cold climates	Durability focuses on the aging process of materials and their performance under long-term environmental stress.

Based on the above research, five hypotheses were drawn:

Hypothesis 1. Low temperature significantly reduces the durability and structural stability of ancient building materials.

Hypothesis 2. Freeze-thaw cycles significantly increase material damage and foundation instability of ancient buildings.

Hypothesis 3. Snow load significantly affects the structural safety of ancient building roofs.

Hypothesis 4. Humidity changes significantly accelerate metal corrosion and wood decay in ancient buildings and affect stone weathering.

Hypothesis 5. High-frequency daily maintenance and effective fire prevention measures can significantly extend the service life of ancient buildings in cold climates.

Distribution and collection of questionnaires

This article designed a total of 17 questions and items, which were distributed through the online questionnaire star, and 631 sets of valid questionnaires were collected. The questionnaire questions are divided into five parts, each part of the questions is based on specific assumptions and is derived from actual cases. All questions are scored using the Likert Scale. Respondents rate the impact of each question from 1 to 5 based on their own experience and opinions.

Table 4 Reliability analysis

Code	Items	Corrected Total Correlation (CITC)	α coefficient with term removed	Cronbach's alpha coefficient
A3	Please comment on the scale question about the repair and maintenance of ancient buildings in Northeast China - 3. What is the effect of low temperature on the durability of wood and stone?	0.632	0.889	0.898
A4	4. How is the stability of building structures affected under low-temperature conditions?	0.616	0.890	
A5	5. To what extent do you think low temperatures affect the physical properties of ancient building materials?	0.617	0.890	
A6	6. How big is the impact of freeze-thaw cycles on the damage of building materials?	0.596	0.891	
A7	7. How is the stability of building foundations affected under freeze-thaw cycles?	0.535	0.893	
A8	8. To what extent do you think the freeze-thaw cycle affects the overall structure of ancient buildings?	0.527	0.893	
A9	9. How much impact does snow load have on the safety of roof structures?	0.556	0.892	
A10	10. How stable is the roof structure under snow load conditions?	0.487	0.895	
A11	11. What differences do you think there are in the impact of snow load on the roofs of ancient buildings in different regions?	0.516	0.894	
A12	12. How much influence does humidity change have on metal corrosion?	0.571	0.892	
A13	13. How does wood decay under conditions of changing humidity?	0.539	0.893	
A14	14. To what extent do you think humidity changes affect stone weathering?	0.612	0.890	
A15	15. How much impact does high-frequency daily maintenance have on the lifespan of ancient buildings?	0.614	0.890	
A16	16. How effective are fire prevention measures in cold climates?	0.576	0.891	
A17	How significant do you think the daily maintenance and fire prevention measures are in protecting ancient buildings?	0.633	0.889	

The validity test refers to the reliability of the questionnaire. Based on the structural validity description, this paper uses factor analysis to conduct the KMO test on the scale questions and obtains $KMO=0.672>0.6$, Bartlett sphericity test $p<0.001$, which is suitable for principal component analysis. From the change of the total variance data explained, the first four principal components with eigenvalues >1 are systematically extracted. After dimensionality reduction, the questionnaire's structural validity is qualified.

Table 5 Table of factor loading coefficients after rotation

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Items	Factor loading coefficient				Commonality (common factor variance)
	Factor1	Factor2	Factor3	Factor4	
A3	0.793	0.147	0.191	0.210	0.732
A4	0.804	0.174	0.139	0.184	0.730
A5	0.827	0.169	0.093	0.214	0.767
A6	0.211	0.154	0.801	0.205	0.751
A7	0.167	0.090	0.839	0.175	0.771
A8	0.090	0.236	0.833	0.080	0.764
A9	0.184	0.712	0.197	0.109	0.592
A10	0.065	0.772	0.099	0.138	0.629
A11	0.095	0.764	0.047	0.226	0.646
A12	0.178	0.223	0.178	0.757	0.686
A13	0.156	0.181	0.128	0.818	0.743
A14	0.329	0.169	0.170	0.730	0.699
A15	0.384	0.387	0.305	0.279	0.468
A16	0.365	0.536	0.181	0.175	0.483
A17	0.453	0.520	0.291	0.084	0.567

Descriptive and correlation analysis

The test data showed that the average value was 3.4-4.1, the standard deviation was about 1, and the median was 4, indicating that the respondents generally supported the hypothesis that low temperature, freeze-thaw, snow accumulation, and humidity have a significant impact on ancient buildings. The correlation coefficient between daily maintenance and fire prevention measures and ancient building repair is 0.787 ($p<0.001$); the correlation coefficient of humidity change is 0.745 ($p<0.001$); the correlation coefficients of snow accumulation, freeze-thaw, and low temperature are 0.708, 0.712 and 0.776 respectively (all $p<0.001$). The above factors are significantly positively correlated with the repair of ancient buildings, emphasizing the importance of considering environmental factors and strengthening maintenance management in the protection and repair of ancient buildings.

As can be seen from Table 10, high-frequency daily maintenance has a significant negative impact on the lifespan of ancient buildings. The article shows that daily maintenance, fire prevention measures, humidity, snow accumulation, freeze-thaw, and low temperature have a positive impact on the repair and maintenance of ancient buildings. The correlation dimension analysis shows that there are complex dynamic influences between the dimensions. These results are of great value to the repair and maintenance practice of ancient buildings in cold regions.

Influence of cold climate on ancient buildings in Northeast China

Selection of building materials

When selecting materials, ancient buildings in the Northeast region first consider materials with good cold resistance such as stone and ceramic tiles, and secondly pay special attention to their thermal insulation performance, such as choosing thick wall materials and adding various thermal insulation materials to the walls. (Wang F.F, 2017) To withstand the pressure of heavy snow, granite, marble, and other materials with high compressive strength are preferred. In cold areas, construction is limited, and the selection of materials for ancient buildings considers construction convenience. With the improvement of environmental awareness, modern ancient buildings in the Northeast try to use sustainable materials, such as EPS, XPS, etc.

Structural form design

Ancient buildings in the Northeast have taken a variety of measures in cold-proof design, including structure, heating, insulation materials, and door and window design. The well-dry-style dwellings resist the severe cold with their compact design. Due to the limited

length of wood, their bays and windows are relatively small, such as the snow village buildings in Heilongjiang. The characteristic "pocket room" layout is also a common ancient building form in Northeast China. The main living space is the king and the warm room. The middle is the main room, the north side is the warm room, and the bedrooms are located on both sides of the main room. This design allows heat to circulate effectively indoors. In addition, the windows of ancient buildings in Northeast China are small and face south or west. Multi-layer glass or paper-pasted windows are used to reduce heat dissipation. The sloping roof structure also uses the "human" shape to effectively prevent wind. (Zhang W.Z, 2017)

Influence of special climate characteristics

The severe cold in Northeast China causes building materials to crack easily, and construction technology needs to be improved. Reduce cracks by using insulation materials, thickening the insulation layer, designing expansion joints, and enhancing the tensile strength of the wall. Strengthen the foundation, select freeze-thaw-resistant materials to prevent corrosion, and design a drainage system to prevent freeze-thaw. Lay a moisture-proof layer on the foundation, and design an internal ventilation design to reduce moisture accumulation and protect ancient buildings from damage.

Connection component design

The mortise and tenon connection is a common connection method in ancient buildings in Northeast China. It gives the building elasticity and self-regulation ability, can resist external forces such as wind and snow, and prevents structural deformation and cracks. As a transitional component between the column and the beam frame, the bracket can strengthen the connection between the beam frame and the column head, effectively transmit and disperse the load such as snow on the roof, and protect the building from damage caused by heavy snow. (Wang Y.Z, 2017)

Repair and maintenance preparation

Before repair, the environment and diseases need to be assessed, and winter inspections should be strengthened. Avoid severe colds, pay attention to insulation and personnel safety. Later, install environmental monitoring and intelligent temperature control and ventilation systems, monitor in real-time, and deal with emergencies to ensure the safety of ancient buildings.

Fund and technology management

The Northeast region is rich in ancient buildings, but they are vulnerable to severe cold climates, and the cost of repair is high. While ensuring quality, cost-effective materials should be selected and economic efficiency should be considered, such as the selection of cost-effective materials (Dai P.F, Liu Z.Y, Sun Z.Y, 2021). The government should increase investment and encourage social fundraising. Use ancient architectural culture to develop tourism and increase income. Strengthen the training and introduction of professional talents for repair, and the government, universities, and institutions will cooperate to train craftsmen and establish a talent pool to support projects.

Conclusin and Discussion

In short, the renovation of ancient buildings in cold regions needs to deal with challenges such as materials, climate, funding technology, maintenance management, and environmental awareness. In the face of cold climates, extreme weather needs to be considered, and thermal insulation, cold resistance, waterproof, and durable materials should be selected. The structure should be stabilized by combining modern technology, and innovation should be made while respecting tradition. Implementation should be prevention-oriented, and inspection and emergency response should be strengthened. The government should increase investment in cultivating talents, introduce social capital, respect the value of ancient buildings, enhance public awareness of protection, and promote participation in protection work.

This article focuses on the impact of cold weather on ancient buildings in Northeast China. Affected by multiple factors such as temperature, snowfall, and wind, the research

results are complex and regional and need to be continuously observed. In the future, it is necessary to deepen interdisciplinary research, combine a variety of technologies and methods, consider geographical characteristics and long-term climate effects, expand research horizons, use advanced monitoring technology, combine historical data and repair data, and comprehensively evaluate the impact of cold climate on ancient buildings to provide a scientific basis for protection work.

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