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Digitalization and Regeneration of Residential Heritage: A Case Study of Dalian Harbour Compound*

Kun Wang[1] , Zhubin Li [2], Ya Zhang[3] , Jian Suo[4]

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Abstract

Purpose: The Dalian Harbor Compound, a historically significant residential heritage site, faces challenges in meeting modern living standards, complicating its conservation and regeneration. Given the lack of efficient architectural survey methods in China, this study explores and applies precise and efficient technologies like laser scanning for architectural surveying, aiming to develop effective renovation strategies. **Research design, data and methodology:** This study breaks through traditional architectural survey methods by using 3D laser scanning point cloud data as the basic data, combined with drone tilt photography and 3D modeling technology, to establish a database of the Harbor Compound buildings. This approach clarified the situation of building deterioration and further refined and supplemented the survey and data statistical methods for this type of building. **Results and Conclusions:** Based on the acquired basic data from the Dalian Harbor Compound, we conducted a strategic study on the directions of local restoration and functional transformation and, according to this research direction, explored the architectural characteristics of such historically significant and valuable residential heritage buildings. A conceptual intent for the renovation of the Harbor Compound within its architectural context has been proposed.

Keywords: Residential Heritage, Digitalization Technology, Regeneration Pathway, 3D Laser Scanning, UAV Oblique Photography

JEL Classification Code: Q01, R21, R31

1. Introduction

The development of residential architecture in China has gone through various periods, with many cities preserving residential buildings of historical significance, such as the courtyard houses of famous figures in Beijing and the lane houses in Shanghai, which carry the city's memories. However, the living conditions in these heritage buildings often do not meet

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1 Kun Wang. Master's Student, Architecture, School of Architecture and Fine Arts, Dalian University of Technology, China. Email: wangkun32316025@mail.dlut.edu.cn

2 Zhubin Li. Associate Professor, Architecture, School of Architecture and Fine Arts, Dalian University of Technology, China, Email: lizhubin128@dlut.edu.cn

3 Ya Zhang. Master's Student, Architecture, School of Architecture and Fine Arts, Dalian University of Technology, China. Email: 360489099@qq.com.

4 Jian Suo. Professor, School of Architecture and Fine Art, Dalian University of Technology. Email: suojian727@dlut.edu.cn

modern residential needs. These buildings, while still in use as residences, face significant challenges in preservation and regeneration due to the lack of basic information, simple original spatial forms, and other issues.

A digitalization-based preservation and regeneration system for residential heritage integrates data and methods using modern information technologies like 3D laser scanning to establish a digital protection system. This involves compiling and analyzing historical documents to create a heritage attribute database, using computer image processing technology for precise analysis of architectural elements, and building a building space database (Yu & Zhang, 2009). This paper proposes preservation and regeneration strategies for residential heritage like the Dalian Harbor Compound based on these databases.

2. Current status of research in China and abroad

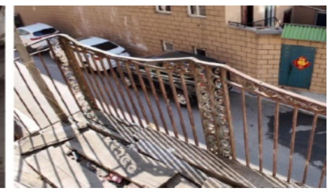
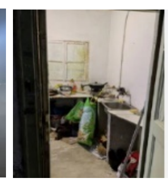
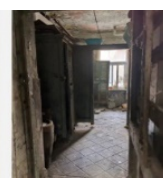
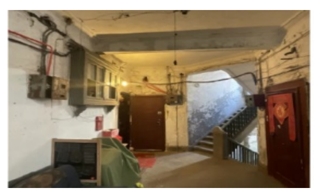
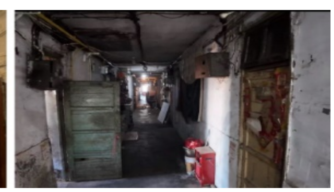
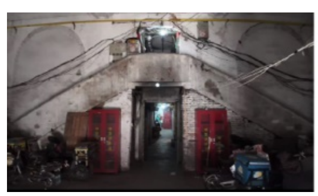
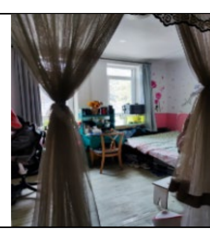
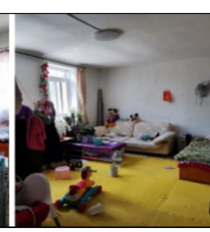
Residential built heritage includes residential buildings with unique historical, cultural and social values, such as Beijing courtyard houses and Shanghai lane houses. Domestic scholars focus on specific conservation practices and technical means, such as Zhang Jiandong, who studied the conservation and reuse of Beijing′ s courtyard houses, and suggested that functional conversion should be carried out on the basis of preserving the architectural appearance and spatial pattern to adapt to the needs of modern life (Zhang, 2015). Meanwhile, in the conservation and regeneration research of residential built heritage, the application of digital technology has gradually become a hotspot, providing fast and high-quality original information for architectural conservation. Three-dimensional laser scanning technology can quickly complete the scanning and measuring work of data points on solid surfaces, obtaining a large amount of accurate and dense three-dimensional coordinate point cloud data (Jia & Hung, 2007), and generating high-precision models for architectural records and restoration design. For example, H. Sternberg et al. used 3D laser scanning technology to scan and model the Kaisersaal and GroberFestsaal, two halls with a long history in the Hamburg City Hall, in 3D (Kersten & Sternberg, 2008). Drone aerial survey technology provides a convenient means of architectural documentation and environmental analysis by rapidly acquiring architectural and environmental data through high-resolution images and videos. Gonzalez-Aguilera et al. investigated the use of drones in historic architectural documentation, demonstrating their advantages in acquiring complex topographic and architectural data (Gonzalez & Martinez, 2017). And the core of residential built heritage regeneration is how to realize modern functional conversion based on the preservation of historical values. The ancient city of Pompeii in Italy records and displays the original appearance of the ancient city through 3D laser scanning and virtual reality technology, so that the public can experience the historical style through virtual tours (Unto & Leander, 2013). In the conservation and reuse project of Beijing′ s courtyards, Zhang proposed that modern facilities be renovated on the basis of preserving the traditional architectural style and spatial pattern, such as adding modern sanitary ware and heating systems to enhance the comfort of living (Bao, 2020). In summary, domestic and international research and practice in the preservation and regeneration of residential built heritage has shown that digital technology has significant advantages in recording, analyzing and displaying historical buildings. Through 3D laser scanning, drone aerial surveying and other technologies, architectural information can be accurately recorded to provide a scientific basis for subsequent restoration and regeneration.

3. Architectural status and research studies

The Dalian Harbour Compound was chosen as a case study because of its unique architectural history as a representative of early 20th century colonial residential architecture in China. Completed in 1920, it is located at No. 1 Xinglin Street (Guan dong Hall) and No. 2 Qingshuang Street (Nanshan Dormitory) in Zhongshan District, and was designed by Takeo Ono of the Design Division of the Manchurian Railway during the period of the Japanese Occupation. The Harbor Compound was in the core of the city planned by the Tsarist Russia and the Japanese in those years, and was originally a family apartment for the s taff of the Manchurian Railway, which was the earliest apartment building in Dalian (Wang & Guo, 2006). It was later conver ted to be used as the family apartments of Dalian port employees and was listed in the list of immovable cultural relics in Dali an. The surrounding area of the Harbor Compound covers important urban nodes such as Dalian Station, Zhongshan Square, Budweiser Years Shopping Mall, and East Harbor, occupying the core area of the city.

The selection of the Dalian Harbor Compound as a case study is representative because its unique architectural history and geographical location reflect broader urban development trends in China. Moreover, compared to other countries, many cities in China have similar colonial buildings. The Dalian Harbor Compound, with its early construction date, distinctive architectural style, and continuous use as residential housing, serves as a prime example of the challenges faced by historic residential buildings in China. The Harbor Compound as a whole covers an area of about 60m x 120m, with Guandong Hall and Nanshan Dormitory standing opposite each other, forming several small courtyards and one large courtyard. The Guandong Hall is a three-story brick and wood mixed structure, while the Nanshan Dormitory is a four-story building. The original architecture is beautifully designed, with a unique facade and detailing that retains a "slightly Spanish American" architectural style. The Harbour Compound is still used for residential purpose, mainly rented to migrant workers, with fewer permanent tenants. Currently, the building faces outdoor problems such as old external surfaces, messy environment in the courtyard, lack of activity space, and congestion caused by the new building, while the internal public space has indoor problems such as piles of debris, chaotic pipelines, dilapidated public restrooms, poor lighting and ventilation, and random additions by the tenants (see Table 1).

Table 1: Problems with the current state of the seaport compound

Problems	Photos of the current situation
1. Aging Facilities: The basic facilities, such as water and electricity supply, have not been updated for a long time and barely meet the needs of the residents, posing inconvenience and safety hazards due to outdated wiring and pipes.	 
2. Cluttered Outdoor Public Spaces: The courtyard enclosed by the two bui ldings lacks reasonable planning and management, with residents setting u p clothes drying poles and other structures, leading to low space quality an d unmet daily needs.	 
3 . Low-Quality Indoor Spaces: The building's spatial layout is unreasonable. Rooms are small, with unclear functional divisions, and the boundaries between public and private spaces are blurred. There are public kitchens and restrooms, but they are small and of poor quality, with low utilization rates.	  
4. Cluttered Corridors: Due to the small rooms, most items are piled up in the corridors, making them overcrowded. The building also lacks age-friendly facilities such as elevators and barrier-free passages, causing inconvenience for the elderly.	 
5. Chaotic Wiring: The interior lacks unified management and maintenance, with residents unauthorizedly connecting water and electricity, leading to chaotic and aesthetically displeasing wiring, posing safety concerns.	 
6. Lack of Protection for Interior Structures: Despite good natural lighting and ventilation, most residents are migrants who only conduct basic maint enance and decoration, without protecting or repairing the interior spaces.	  

4. Technical Methods and Equipment

In traditional building surveying, steel tapes and levels are used to measure the positions of characteristic points and lines in building plans, elevations, or sections, and then draw linear characteristic maps based on the geometric relationships of the design and existing conditions (ESRI, 2004). As surveying technology has advanced, building surveying techniques have also developed, incorporating tools like GPS, total stations, robotic total stations, and close-range photogrammetry. These technological improvements have enriched surveying methods, but they still cannot fully meet the high-precision requirements for surveying certain buildings (Yu & Zhang, 2009). In contrast, 3D laser scanning and UAV oblique photography distinguish themselves from traditional single-point positioning measurements, line and point surveys, and photogrammetry techniques. They can penetrate any complex on-site environment to quickly complete the scanning measurement of surface data points, obtaining a large amount of precise and dense 3D coordinate point cloud data. This complex and irregular 3D data is then fully captured into the computer to construct a 3D model of the surface of the entity (Jia & Hung, 2007).

This study uses the Omni SLAM backpack 3D laser scanner and DJI UAV to collect 3D data (see Figure 1). The 3D laser scanner is equipped with a large field of view (FOV) multi-fisheye camera, which can cover the environment's stereo image at 360°, simultaneously controlling and shooting, and compensating for camera shake in real-time. The 21-megapixel panoramic still photos provide clearer images, and the excellent noise reduction and precise color reproduction capabilities allow for more accurate target tracking in automatically generating precise geometric 3D point clouds (see Figure 1).

This paper utilizes point cloud data to establish a complete and accurate digital archive of the Dalian Harbor Compound. The digital records provide a basis for inspection and repair, allowing the reconstruction of lost or damaged historical sites of the Dalian Harbor Compound to restore its original appearance. Compared to other surveying methods, 3D laser scanning technology offers the following advantages: (1) Speed: it can collect thousands to hundreds of thousands of points per second; (2) Information volume: the data includes numerous measurement points, each with three-dimensional coordinates and laser reflection intensity values, which can realistically reflect the appearance of objects, making it especially suitable for measuring objects with complex shapes; (3) High precision: it can achieve millimeter-level accuracy; (4) Non-damaging to the surveyed objects: using non-contact measurement; (5) Cost and time efficiency: it can quickly complete comprehensive surveying with less manpower; (6) High value of data: the digitized information can be preserved long-term and widely applied (Yu & Zhang, 2009).

However, during the data collection process, several challenges were encountered. For instance, the complex terrain and the surrounding environment of the Dalian Harbor Compound, including narrow spaces and obstructed views, posed difficul ties in achieving consistent and accurate scans. Additionally, the varying heights and orientations of the buildings required meticulous planning of UAV flight paths and laser scanning routes to ensure complete coverage without missing any critical details.

To overcome these challenges, multiple equipment adjustments and survey site experiments were conducted, setting the sampling density of the 3D laser scanner to 0.0002m. The team carefully selected an appropriate backpack-mounted 3D laser scanning route and determined the conversion of xyz coordinates (see Figure 3). The UAV scanning survey was arranged to achieve 360° coverage without blind spots, ensuring that all facades and components of the buildings in the Dalian Harbor Compound were fully captured in the point cloud data, thereby avoiding potential issues like gaps after data stitching.

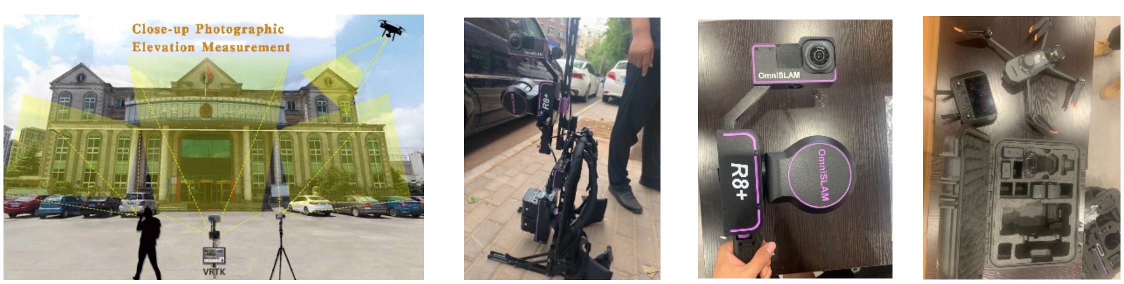


Figure1. Mappingmethodsandequipment(Redrawnbytheauthor

5. Data Collection and Processing

During the surveying data collection of the Dalian Harbor Compound, overall point cloud data was obtained using 3D laser scanning and UAV scanning survey technologies. Subsequent preprocessing of the data was carried out using software such as OmniSLAM Viewer, OmniSLAM Works, and Dasworker. This process involved further coordinate transformation and texture mapping onto the 3D model, resulting in a final visualized 3D model that meets the requirements for establishing a building space database for the Dalian Harbor Compound (see Figure 2).

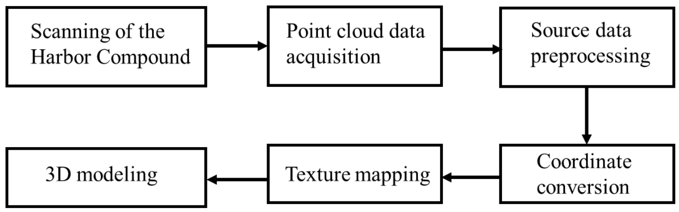


Figure2. Overallflowofdataacquisitionandprocessing

5.1. 3D Point Cloud Data Collection

During the data collection process, the terrain conditions and relative distances of the Dalian Harbor Compound (Guandong Hall and Nanshan Dormitory) were taken into account. Multiple equipment adjustments and survey site experiments were conducted, setting the sampling density of the 3D laser scanner to 0.0002m. An appropriate backpack-mounted 3D laser scanning route was selected, and the conversion of xyz coordinates was determined (see Figure 3). Based on this, outdoor points A and B were determined to meet the line-of-sight requirements and conform to the UAV surveying distance (Figure 3). The UAV scanning survey was arranged to achieve 360° coverage without blind spots, ensuring that all facades and components of the buildings in the Dalian Harbor Compound were fully captured in the point cloud data, thereby avoiding potential issues like gaps after data stitching.

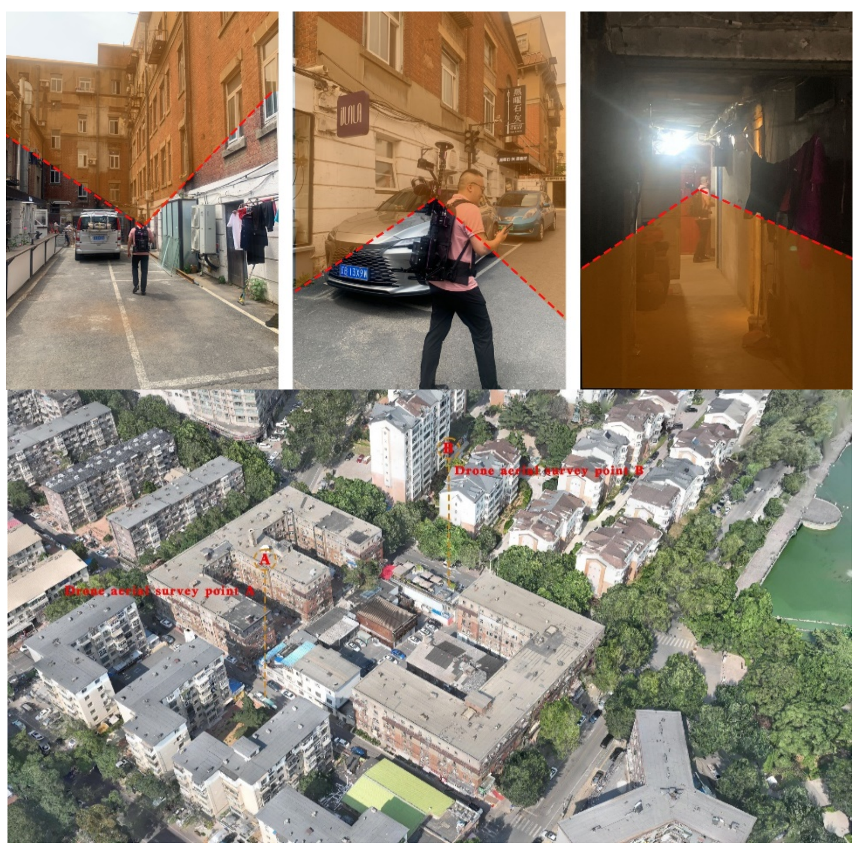


Figure3. Mappingprocess

5.2. Survey Data Processing and Visualization

Point Cloud Data Stitching: For the point cloud data obtained from the Dalian Harbor Compound, the most common multi-station stitching method was used. The OmniSLAM Works software was utilized for the initial preprocessing of the point cloud data collected by the 3D laser scanner. In the OmniSLAM Works software, stitching was achieved by selecting more than three common control points from the overlapping parts of data from two different survey points, ultimately generating a complete point cloud set. After stitching, the duplicate data was merged into a single layer using the software's merge function to avoid data redundancy and inconsistency.

Source Data Preprocessing: The preprocessing work after point cloud data stitching primarily involved removing incorrect data to obtain valid data. Due to the presence of trees and other structures around the Dalian Harbor Compound during the scanning process, some erroneous data points were recorded. To prevent issues like broken surfaces during subsequent model construction, manual elimination and error removal using OmniSLAM Works were performed on the source data, resulting in high-quality point cloud data.

Coordinate Transformation: Since multiple locations were used for data acquisition during the data collection process, the angle, height, and orientation of the equipment varied with each scan. Therefore, the separate equipment coordinates systems in each building scan needed to be merged through multi-station stitching and transformed into a unified standard geographic coordinate system. Global control points were added to meet the needs of subsequent modeling.

3D Modeling: Using the model construction modules in OmniSLAM Works and Dasworker software, the preprocessed data was used to reconstruct data models. The real images of the buildings, captured by UAVs, handheld cameras, and built-in cameras, were matched to the corresponding points in the 3D data, creating a realistic 3D representation of the Dalian Harbor Compound. The digital model can achieve multi-angle sectional displays, with horizontal sections generating floor plans and vertical sections generating cross-sectional views (see Figure 4). Additionally, using the measurement functions of OmniSLAM Works and Dasworker software, further geometric data such as surface area, length, width, and height of the buildings can be obtained. Finally, the relevant data can be exported to traditional drawing software like AutoCAD and ArcGIS for establishing a building database and conducting research in subsequent regeneration design and other aspects (see Figure 4).

Figure 4. 2D and 3D mapping

6. Digital Preservation and Utilization of the Dalian Harbor Compound

6.1. Database Construction

The digital preservation and utilization of residential heritage buildings require integrating spatial location information and attribute information to build a comprehensive building spatial and attribute database. This building spatial attribute database includes 3D image data, such as UAV oblique photography images, and vector data that represent the boundaries and internal structures of the buildings using geometric elements like points, lines, and surfaces. The data structure explicitly stores topological relationships to enable fast retrieval and querying. The vector data also include point cloud data and 3D models obtained from laser scanning. The attribute database collected through surveying covers attribute information related to spatial data, such as point cloud attributes, building area, and geometric composition. The structural design should facilitate easy traversal and quick access, with the creation of corresponding databases and tables (see Table 2).

Table 2: Structure of the building information database

Point cloud database structure		
Field	**Name**	**Type Name**
Id	int	ID number
X	Float	X-coordinate
Y	Float	Y-coordinate
Building information database structure		
Field	**Name**	**Type Name**
Layers	Int	Number of floors
FH	Float	Height
DH	Float	Door Height
Date	Date	Building time
IMG	Image	Image Information
Causality	Length, width and height	External Dimensions
Remark	Char	Remarks

6.2. Digital Preservation and Revitalization System for the Dalian Harbor Compound

Utilizing the point cloud data and oblique photography survey data obtained previously, a comprehensive digital preservation system has been designed for the Dalian Harbor Compound (see Figure 5). This system not only provides solutions and technical services for digital preservation but also lays the groundwork for restoration planning and implementation. By combining databases, virtual reality technology, and precise measurement tools, the system enables an informed approach to restoring and revitalizing historical buildings.

Using ESRI's ArcGIS Engine development platform, the preservation system integrates a set of core ArcObjects packages, including user interface components (controls and tools) and a programmable object library. These objects are platform-independent, allowing the reconstruction of 3D models based on relevant survey data. This integration supports universal analysis, visualization, and querying of 3D models, which can directly inform decisions about the repair, conservation, and adaptive reuse of heritage buildings (ESRI, 2004).

To illustrate, the point cloud data obtained from 3D laser scanning has been used to identify precise areas of structural deterioration, such as cracks, material degradation, and deformations. These findings are linked with historical data to develop actionable restoration plans. For instance, by analyzing the scanned data, specific elements of the building that require immediate repair can be targeted while preserving the overall structural integrity and historical authenticity.

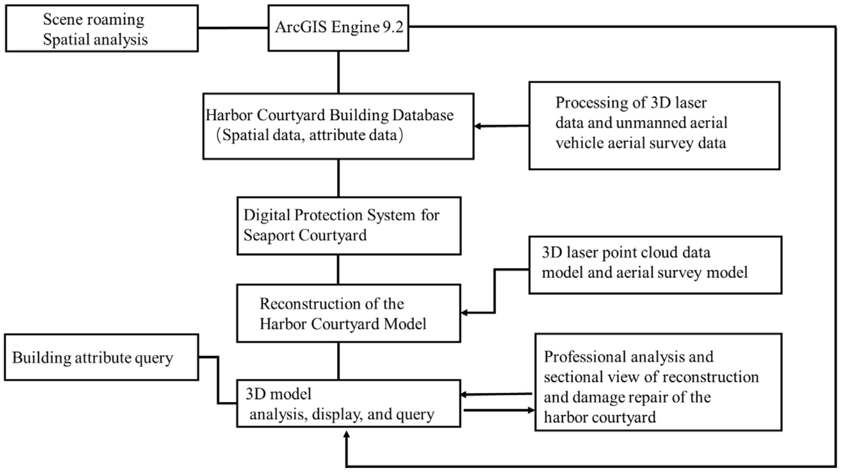


Figure5. Architecturaldigitalpreservationsystemdesignframework

7. Regeneration Strategies and Methods for the Dalian Harbor Compound

Based on the digital system established through 3D laser scanning and UAV oblique photography techniques, this sectio n proposes feasible regeneration pathways to address the identified issues. For the deterioration of the building structure, loc al repairs and restorations are necessary. In response to regional needs, the current conditions should be fully utilized for fun ctional repurposing and renovation, ensuring deep integration with the urban core area. For the current status of the building obtained by UAV inclined photograph, relevant data are saved, and the inclined photographic images from different viewp oints are visualized and processed to establish a database of corresponding images.

Combining the image information obtained from UAV tilt photography, 3D laser scanning is utilized to establis h an information database of the building (see Table3-4), and then corresponding regeneration strategies and direct ions are proposed.

Table 3: Laser Scanning Acquisition Status Issue

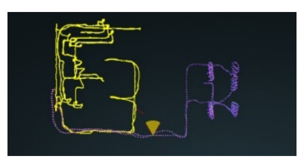
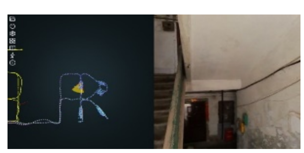
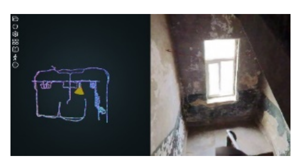
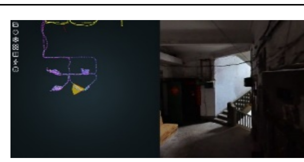
Buildings / Process	Exterior of the building	Inside the Guandong Hall	Inside the Nanshan Dormitory
Mapping paths			
Status of mapping 1			
Status of mapping 2			

Table 4: Guandong Hall and Nanshan Dormitory Buildings information database structure

Guandong Hall Building information database structure		
Field	**Name**	**Type Name**
Layers	Int	5
FH	Float	2.150\3.300
DH	Float	2.100
Date	Date	1920
IMG	Image	2024.7
Causality	Length, width and height	59.3\40.3\19.3
Remark	Char	Family Apartments
Nanshan Dormitory Building information database structure		
Field	**Name**	**Type Name**
Layers	Int	5
FH	Float	3.300
DH	Float	2.100
Date	Date	1920
IMG	IMG	2024.7
Causality	Length, width and height	60.6\42.6\17.0
Remark	Char	Single Apartment

Partial Restoration: Detailed restoration plans are formulated based on the high-precision 3D laser scanning data. These include restoring damaged facades, repairing aging materials, and updating public amenities such as courtyard seating and rest facilities. The plans ensure the buildings' historical appearance is preserved while meeting modern safety and durability standards.

Functional Conversion: Leveraging the spatial database, interior spaces are modernized to meet contemporary needs. This includes converting outdated interiors into studio apartments, cultural and creative spaces, or small commercial units, ensuring deep integration with the surrounding urban area. Hardscaping elements in the courtyard, such as pathways, are updated for accessibility and functionality.

Optimizing Space Layout: The spatial data informs the redesign of internal layouts to improve usability. Small and irregular rooms are expanded or restructured, while non-load-bearing walls are modified to create open, flexible spaces. Public and private areas are clearly delineated to enhance functionality, such as transforming communal kitchens into private kitchens.

Community Integration: Strengthening ties with the surrounding urban environment, greenery and landscaping are added to courtyards to create vibrant, communal spaces. This promotes social interaction and enhances the overall aesthetic appeal of the compound.

The integration of these strategies, supported by the comprehensive digital preservation system, ensures the revitalization process is both evidence-based and sensitive to the site's historical value.

8. Conclusion and Outlook

In summary, the application of 3D laser scanning and UAV oblique photography has accurately recorded the basic architectural information of the Dalian Harbor Compound. The digital data obtained has highlighted the needs and challenges for the compound's renovation and regeneration, providing a scientific basis for subsequent restoration and functional transformation. The digitalization and regeneration of the Dalian Harbor Compound are not only crucial for preserving historical and cultural heritage but also key to achieving sustainable urban development. Additionally, adapting historical residential heritage sites like the Dalian Harbor Compound to modern needs by functional conversion and community integration breathes new life into these historical buildings, enhancing their value and significance in contemporary society. It is hoped that this study will provide valuable references for the digital regeneration of similar residential heritage sites.

In summary, the application of 3D laser scanning and UAV oblique photography has provided precise and comprehensive records of the architectural information of the Dalian Harbor Compound. The digital data obtained not only identifies the current conditions, needs, and challenges for the compound's renovation and regeneration but also serves as a robust scientific basis for the subsequent processes of restoration and functional transformation.

The digitalization and regeneration of the Dalian Harbor Compound are essential for preserving its historical and cultural significance, demonstrating how modern technologies can bridge the gap between heritage conservation and urban development. By integrating advanced technologies into the regeneration process, this study underscores the importance of precision in data acquisition, systematic analysis, and evidence-based planning in ensuring both the preservation of architectural integrity and the enhancement of residential usability. Beyond preserving the historical appearance, the regeneration strategies explored in this study emphasize functional adaptation and community integration. Transforming the compound into modernized, functional spaces not only addresses the current issues of deterioration but also redefines its role in the urban fabric as a vibrant, sustainable, and inclusive space. The study illustrates that the combined use of digital preservation systems, including 3D modeling, attribute databases, and virtual reality, can facilitate efficient resource management, informed decision-making, and better stakeholder engagement in heritage projects.

Looking forward, the findings of this research hold broader implications for similar heritage sites. The methodologies and strategies presented can serve as a replicable model for the digital preservation and revitalization of other residential heritage buildings, particularly those in dense urban contexts. Furthermore, this study highlights the potential of integrating community-centric approaches and green urbanism principles into heritage regeneration projects to foster social cohesion and environmental sustainability. It is hoped that this study will inspire further interdisciplinary research and cross-sector collaboration, enabling the digital regeneration of historical residential heritage sites to become a standard practice. In doing so, we can ensure the harmonious coexistence of cultural preservation and urban modernization, enhancing the livability and cultural vitality of cities in the 21st century.

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