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Development of YOLOv8 and Segment Anything Model Algorithm-Based Hanok Object Detection Model for Sustainable Maintenance of Hanok Architecture

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Abstract: A Hanok refers to a traditional Korean architectural structure. Construction structures undergo gradual, rather than instantaneous, transformations due to material degradation and deterioration in joint durability. Moreover, the detection of a structural problem by a nonexpert has severe implications for the safety of the structure. In particular, the precise effects of natural disasters, including storms, earthquakes, heavy snowfall, and structural defects, on structures are hard to determine. Additionally, manuals are limited by their reliance on quantitative assessments, which can pose difficulties for nonspecialists when it comes to recording numerical data. To solve this problem, 3D scanners have been widely employed in evaluating Hanoks, particularly those assigned as cultural heritage by the government. While those assigned as cultural heritage assets are systematically managed by experts and through budgets, the management system for Hanoks inhabited by the public has been overlooked. To fill this gap, this study focused on digital devices that are accessible to nonexperts as replacements for professional 3D scanners. Specifically, data from photos of a Hanok taken with smartphones were extracted to generate objective numerical data. AI training data for Hanoks were used to train the YOLOv8 algorithm and Segment Anything Model (SAM). The leaning values of columns, which constitute a fundamental structural component of a Hanok, were calculated using photographs that precisely captured the columns. The direction and distance of the column's movement were extracted for visualization. To ensure the reliability of these values, the Hanok under investigation was 3D-scanned. Comparing the numerical values revealed a negligible margin of error, which confirmed the reliability of the photographic data values. Five-tier safety states (good, observation, caution, danger, and very dangerous) were defined based on the column movement distance by analyzing the real measurement data of government-managed Hanoks and used to visualize the structural condition of Hanoks. Therefore, nonexperts can determine the structural safety of a Hanok using objective numerical data, even in situations where its progressive deformation is not readily apparent. Objective numerical analysis based on reliably collected data allows nonexperts to accurately diagnose structural safety, thus facilitating prompt and suitable actions. The results of this study can serve to enhance the stability and longevity of Hanok structures, thus facilitating sustainable maintenance and management.

Keywords: Hanok; measuring and monitoring sustainability; you only look once (YOLO); Segment Anything Model (SAM); deep learning; 3D scanner; Python; Exif

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1. Introduction

A Hanok refers to traditional Korean residential architecture. As the embodiment of the Korean traditional lifestyle and culture, it has been continuously preserved and developed. The Korean government has endeavored to elevate the national cultural standard based on Korean traditional architectural culture to enhance its national brand reputation and image. The government implemented a comprehensive plan for promoting the "Han Style" in 2007, researched Hanok architectural standards in 2009, and established the National Hanok Center in 2011. Similarly, local governments organized the preservation and

promotion of Hanoks in 2002 (Jeonju) (Figure 1), Seoul's Hanok Village business promotion project in 2008 (Seoul), and research in the direction and standards for the new Hanok Village pilot project in 2009.



Figure 1. Hanok Village in Jeonju. With around 800 Hanoks, Jeonju Hanok Village is a leading tourist destination for traditional cultural experiences in Korea. According to Jeonju statistics, the number of tourists recorded was approximately 14.42 million in 2023, compared to 3.5 million in 2010.

On 18 February 2010, "Hanok" was formally defined via the amendment of the Enforcement Decree of the Building Act, which aimed at preserving and advancing the traditional residential culture of Hanoks. Commencing in May 2010 with the "New Hanok Plan for National Dignity Enhancement", the Hanok promotion policy has since been taking shape. This cooperative initiative involved six ministries and agencies: the Presidential Commission on Architecture Policy; Ministry of Land, Infrastructure and Transport; Ministry of Culture, Sports and Tourism; Ministry for Food, Agriculture, Forestry and Fisheries; Ministry of Foreign Affairs Republic of Korea; and Korea Forest Service [1].

Since the announcement of the "New Hanok Plan", a total of 9727 Hanoks have been constructed between 2011 and 2021, which averages to approximately 970 Hanok buildings per year. Moreover, Hanok constructions constitute approximately 0.4% of the approximately 250,000 building permits and approvals issued annually in Korea [2].

The "Act on the Promotion of Architectural Assets, including Hanok" was enacted in 2015 to promote national architectural culture and strengthen competitiveness. The precise details may vary with local governments—Jeonju, for instance, has implemented a policy since 2020 that provides subsidies within the range of two-thirds of the construction costs for up to KRW 50 million for the construction, extension, and renovation of Hanoks (Figure 2).

However, the market for Hanoks is small, and Hanoks have not yet been designated a specific category in construction-related legislation, including in the Construction Industry Basic Act. Hanoks are primarily maintained by the Cultural Property Repair Business according to the Cultural Heritage Protection Law. However, their construction is categorized as general construction rather than cultural property, which makes the Hanok market a gray area. Moreover, Hanok-related policies are still in their infancy, which complicates the situation further [3].



Figure 2. Hanok renovation. This photo depicts a Hanok in Jeonju Hanok Village; the roof was retained, while the columns were replaced with new timber. While old Hanoks are often demolished and reconstructed, some are instead renovated to preserve their original appearance as much as possible.

In particular, Hanok architecture requires designers to draw the plans and builders to construct them. However, due to the lack of specialized training for designers, Hanoks have been built by relying on experts in the construction field. Professional qualifications for cultural heritage construction are absent, and only technical certificates are issued by the Cultural Heritage Administration. In response, the government has operated a Hanok Specialist Cultivation Project for architects since 2011. The project aims to cultivate a virtuous industry cycle that can give professionals the expertise to supply quality Hanoks [4].

As previously discussed, national policies have sought to develop experts to meet the demand for Hanoks, but these experts are not easily accessible to general Hanok residents. Hanok maintenance is the most crucial aspect after new construction or remodeling. A Hanok is built with natural materials, including wood and earth, rather than the concrete or steel used in modern structures, making its maintenance challenging for general building experts.

The Seoul government has been operating the Hanok Support Center since 2015, which offers the Hanok 119 Service for Hanok on-site inspection and repair consultation to diagnose and support damage in Hanoks. Moreover, the center developed a maintenance manual that provided residents with the knowledge and skills required to conduct self-inspection and perform maintenance measures for their Hanoks.

Although maintenance manuals exist, a Hanok naturally undergoes deformations, such as twisting, which are difficult to detect with the naked eye. The visible presence of such deformation suggests severe damage in the structure (Figure 3). Hanoks designated as national heritages are overseen by the government, and Hanok experts directly measure and assess structural deformations using costly equipment, such as 3D scanners and inclinometers.

Recently, uncommon external loads, such as earthquakes and typhoons, have been increasing in Korea. Moreover, their intensities have been gradually increasing, which poses safety concerns [5]. An earthquake in Gyeongju in 2016 damaged 100 national heritage sites, and an earthquake in Pohang in 2017 damaged 31 national heritage sites [6].



Figure 3. Yeosu Jinnamgwan National Treasure. The photo depicts a government-managed Hanok; the leaning in its columns was identified during a regular survey by the Cultural Heritage Administration's National Research Institute of Cultural Heritage. Steel braces were installed to temporarily prevent further leaning, and the Hanok was completely disassembled for repair in 2016.

National heritage Hanoks managed by the government are overseen by relevant experts, and Cultural Heritage Care Centers are present in each region. They assess damage and diagnose and maintain the structures. However, this is not the case for Hanoks inhabited by the general public.

Unlike experts in general modern structures, those in Hanok construction are not easily accessible to the general public residing in Hanoks. As digital measuring equipment used to preserve cultural heritage is often limited to professionals, identifying deformations in non-heritage Hanoks due to natural disasters or aging is challenging. Additionally, because even experts conducting visual inspections can determine the safety risk of a structure only after severe deformation, identifying whether the continual, minute movements of columns are progressive is challenging without digital equipment.

Therefore, this study aims to develop a system for detecting structural deformations in Hanoks. The most accessible approach involves using smartphone photos to detect deformations, which does not require expensive equipment. The research approach can be summarized as follows (Figure 4). The research was conducted in five stages: data collection, data calibration, image recognition, output generation, and verification. The initial data collection stage required collecting Hanok training data. This study utilized AI data provided by the Korea Intelligence Information Society Agency. AI training data (14 fields) from the Intelligent Information Industry Infrastructure Construction Project and those of domestic and foreign institutions/companies are publicly available. Hanoks with standard structures were used for this research. The photos used for the experiment were taken with an iPhone 15 Pro Max by the authors. The data calibration stage involved correcting any tilting that occurred when taking photos. To correct tilts, ExifTool version 12.5 was used to extract accelerometer values from the photo properties. The third stage involved training the model to recognize Hanok objects with AI training data and Hanok photos taken by the authors. YOLOv8m was used for object recognition, whereas SAM_vit_h_4b8939 was used for boundary detection and movement recognition. The fourth stage involved generating outputs, and the column movements were quantified and represented in plan and elevation views. The safety level can be measured from the column movement metrics. In the fifth stage, the subject structure was measured with a 3D scanner to ensure the reliability of the final results. This involved comparing the 3D-scanned measurements with tilt values from photos to verify their accuracy. A performance evaluation was then conducted to determine the optimized photo pixel range.

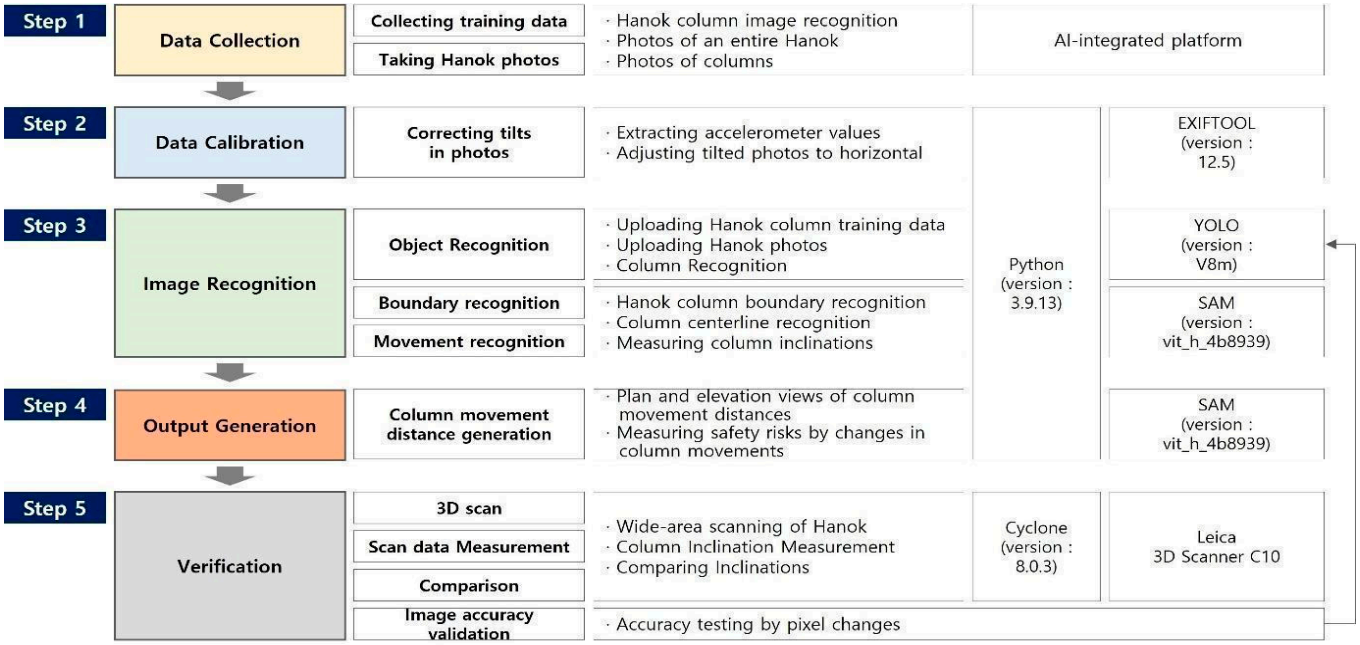


Figure 4. Research flow. The research flow consists of five stages, and the details of each stage and the corresponding programs used are specified in this figure.

2. Theoretical Considerations

2.1. Hanok Structure

Korean architectural culture has mainly developed around wooden structures. Hanoks are created by preparing individual wooden components and connecting them through joinery techniques, joining, and fitting, which are then assembled as a single structure [7]. Hanoks are characterized by post-and-lintel construction using pure wooden material without metal fasteners, such as nails or bolts; fastened vertical and horizontal components; and added layers by intersecting along the x and y axes using the same fastening methods (Figure 5).

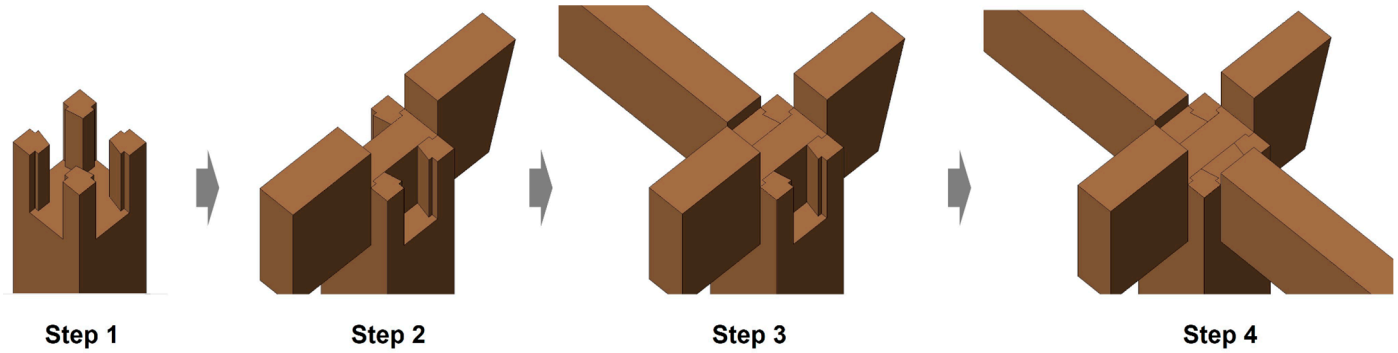


Figure 5. Hanok joinery techniques. Step 1: Trimming the upper part of a column in four directions. Step 2: Linking the horizontal component, Boaji, to the upper part of the column in the *X*-axis. Step 3: Linking the left horizontal component, Changbang, in the *Y*-axis. Step 4: Linking the right horizontal component, Changbang, in the *Y*-axis.

The foundation of a Hanok is built from the ground up. This represents not only structural hierarchy but also prevents moisture from the ground and rainwater flowing down from the roof from reaching the wooden parts. The foundation is formed by tamping the earth, after which a foundation stone is placed on top. Columns are then placed on the foundation stones without any fixed metal hardware (Figure 6).



Figure 6. Mongsimjae in Namwon. Roof section, frame section, foundation section. Hanoks can be categorized into roof, frame, and foundation sections.

Columns are placed on foundation stones, and the structure is formed using wood. Because columns are placed on foundation stones without metal fasteners or bolts, they can be vulnerable to movement under horizontal pressure. To increase friction, the wood is trimmed to match the natural shapes of the stones without processing, a technique called Grengijil (Figure 7).



Figure 7. Foundation stone and column. The figure depicts how a wooden column is carved to match the shape of the foundation stone.

The layout of a Hanok is expandable, and various floor plan configurations can be accommodated. After erecting columns, which are the vertical components, in accordance with the floor module, horizontal components are placed across the columns to complete the structure (Figure 8). The roof load is proportional to the building span and height, and the higher it is, the more columns that will be required. The main structures are named according to their scales, for instance, 3-Ryang, 5-Ryang, 7-Ryang, and 9-Ryang houses [8].

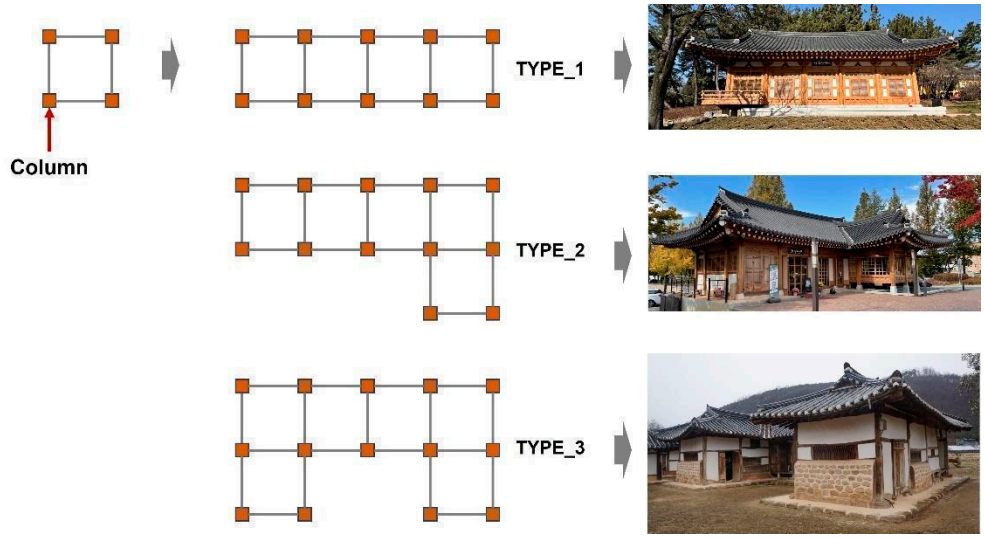


Figure 8. The properties of a Hanok layout. Hanok layouts are characterized by their rectangular modules. TYPE_1 extends in one direction, TYPE_2 extends along the front of a building, and TYPE_3 has a symmetrical floor plan.

After the main wooden structure is constructed, the roof is made by first tamping the earth and then laying tiles, or Giwa, on top. Compared to Western-style wooden buildings, the roof loads of a Hanok are considerably higher (Figure 9). Because cross- and unidirectional joint techniques with wooden joinery rather than fixed metal fixtures are used, roof loads are utilized to reinforce the rigidity of the joined parts. This heavy load is crucial in resisting earthquake or wind deformations [9].

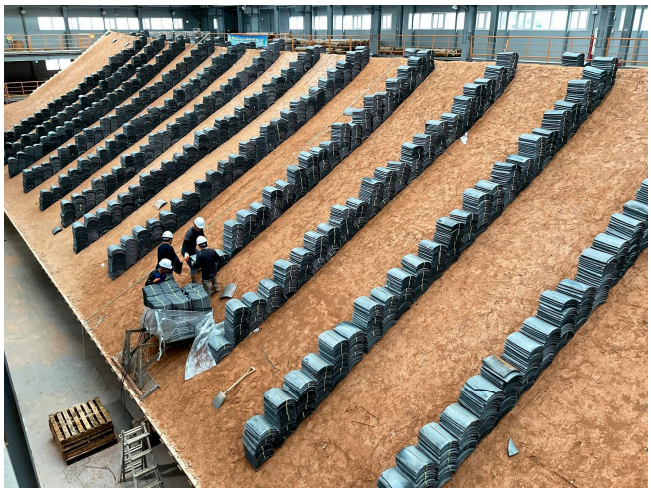


Figure 9. Roof construction of Yeosu Jinnamgwan. The figure depicts the laying of Giwa after tamping the earth on a Hanok roof.

2.2. Hanok Deformations

The combination of various forces, including tension, compression, shear, bending moments, and torsional moments, requires Hanok structures that can effectively resist them. In particular, because forces can concentrate on a small surface, such as a component carved to cross other components, these components should be specifically designed to withstand such forces. Moreover, natural woods, which are the primary materials used in Hanok construction, can gradually contract or relax, leading to deformations (Figure 10) [8].

Ensuring that the Hanok is comfortable and durable also requires awareness among residents regarding the repair and management of common defects. Unlike apartment

complexes and other shared buildings, Hanoks lack maintenance records. Therefore, improper maintenance leads to deterioration in livability and premature structural aging, which decrease the initial performance of the building [10].

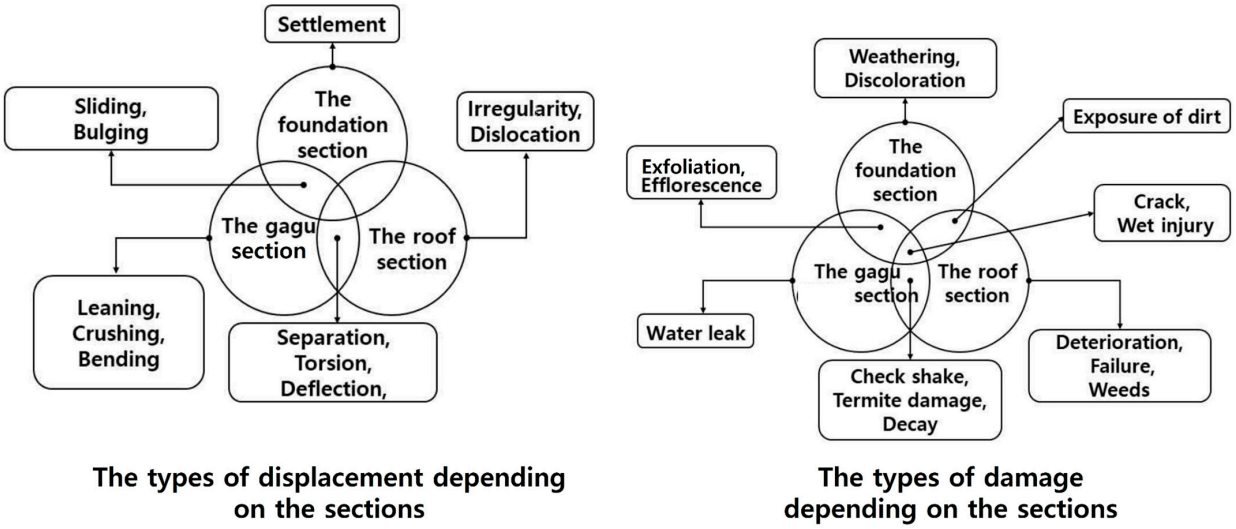


Figure 10. Types of main displacements and damages in Hanoks [11].

Moreover, the wood in Hanoks tends to deform more than stone or concrete, which means that maintenance should be performed more carefully. While many Hanok educational programs target the general public, there are limitations to direct management. For instance, while maintenance manuals or institutions are present in large metropolitan areas, such as Seoul and specific districts where Hanoks serve as tourist resources, maintenance in other areas is challenging.

Deformations in Hanoks can be the result of natural disasters, including earthquakes or structural aging and defects. For example, the 2007 repair report of the Daeungjeon Hall of Hwaeomsa Temple in Hadong documented that the front foundation stone settled following an earthquake. Measurements indicated that the columns sank as the front foundation subsided, leading to the building leaning forward. The damage was recorded to be a result from an earthquake with a magnitude of 5 (Figure 11).

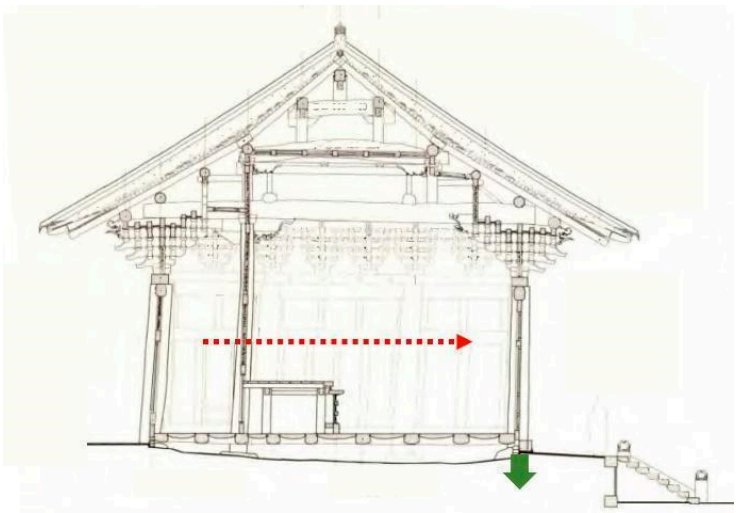


Figure 11. The longitudinal section of Daeungjeon in Hadong Hwaeomsa Temple [12]. The longitudinal section of the Hanok indicates that its column is leaning toward the red arrow, and another column is settled in the direction of the green arrow.

Hanoks are characterized by symmetry and stability, as the wood materials are interlocked. However, a defect in one of the parts can lead to a domino effect of instability, resulting in the deformation of the structure (Figures 12 and 13). While construction and repair techniques for Hanoks are well developed, maintenance techniques that can detect structural problems early have not been highlighted. Had earthquake damage been identified in the early stages, the leaning of the building could have been prevented by reinforcing the ground. Therefore, detecting and addressing deformations early is an effective maintenance strategy for minimizing damage to Hanoks.



Figure 12. Daeungbojeon in Haenam Mihwangsa Temple [13]. Structural deformation, indicating differences in the heights of the roof's left-side (A) and right-side (B).

Detecting structural defects early is essential in modern buildings as well. While damage, deformation, and collapse as a result of structural defects and their causes are known, failures in prevention commonly occur because the causes and effects are understood, but the process is not. The process requires documentation, which has evolved from analog to digital methods. This study aims to find the most efficient building management measures within the context of cause and effect.



Figure 13. Sebyeonggwan in Tongyeong [13]. The roofline is not a regular curve due to roof sag.

2.3. Measurement and Documentation of Hanoks

Where wooden components in Korean traditional wooden structures are placed and their forms gradually evolve over time, rather than artificial modifications like restoration. The causes vary according to the inherent properties of wood components, joinery states, and building usages. The degree of changes can be too subtle to detect or so severe that they cause serious structural impacts on buildings [14].

Building documentation is not only necessary for research but also for the repair and restoration of the parts damaged by natural disasters. In Korea, actual Hanok measurements were initiated through the repair of the Muryangsujeon of Buseoksa Temple in 1958. Previously, Hanoks were measured and documented entirely manually. Manual measurements introduced numerous errors, including those from the measuring tool standard, human error in reading measurements, deformations of tools, and errors in applying these tools to the components (Figure 14) [15]. Digital methods have thus been developed to overcome limitations in manual measurements. Manual paper drawings shifted to 2D digitalization, and high-quality color images replaced black-and-white photos. Regarding measurement methods, measurement time and accuracy have been enhanced via the introduction of state-of-the-art equipment, including 3D scanners (Figure 15) [16].



Figure 14. Manual Hanok measurement. Experts manually measure Hanoks using measurement tools, which is likely to introduce errors among different experts.



Figure 15. Hanok measurement using a 3D scanner. A 3D scanner does not require physical measurement tools.

A 3D scanner was used in 2001 to measure the cultural heritage of Hanoks in Korea. Its accuracy outperformed that of manual measurements, leading to measurement using 3D scanners being mandatory for cultural heritage Hanoks (Figure 16). However, such measurements are performed by cultural heritage experts, who are managed by the government. The general public, in contrast, is not aware of how and which parts to record during manual measurements. Measurement methods vary among experts, and cost can be a decisive factor. In addition, 3D scanners are not used for all measurements and recording in Korean cultural heritage Hanoks. Specifically, only the highest-grade Hanoks are measured using 3D scanners due to the financial cost of 3D scanners and experts. Because the burden of cost is felt even in projects that are overseen by the government, conducting measurements on Hanoks where ordinary people reside using a 3D scanner is challenging.

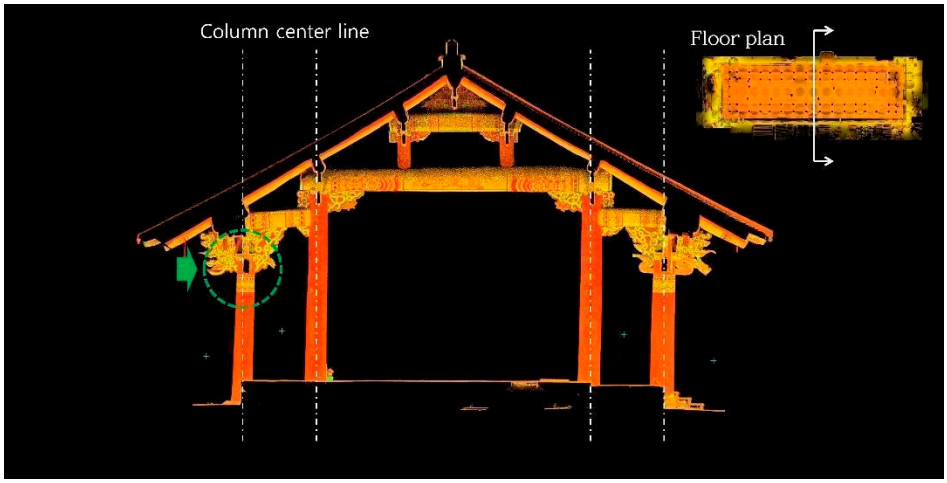


Figure 16. Hanok cross-section. The cross-section of a Hanok was measured with a 3D scanner, which allows for precise measurements. The dashed green circle depicts an area leaning toward the green arrow.

To determine the progression of column leaning, monthly or annual measurements should be compared to detect movement. If the column leaning is visible to the naked eye, structural stability is already severely compromised, and such a progression of movement is indiscernible by sight alone. This requires precise measurements using 3D scanning equipment, which is beyond the reach of ordinary people dwelling in Hanoks.

2.4. You Only Look Once (YOLO)

Temporal and environmental effects decrease the performance of Hanok structures, and cracks of various sizes can occur. Wood is sensitive to moisture, and it can twist if not sufficiently dried. Accordingly, inspectors perform visual inspections using measuring tools when they expect building deformations during their regular inspections. However, the results from visual inspections can vary depending on the inspector's subjectivity, making it challenging to compare the results with previous inspections, as the differences in pictures need to be spotted monthly with the naked eye. Therefore, this study aimed to leverage deep learning methods to overcome the limitations of inspection methods, thereby increasing the objectivity of the deformation results.

The you only look once (YOLO) algorithm was used to train a model to recognize the main structural component of Hanoks, namely the roof surface, which is the largest area on the façade and columns. YOLO has been garnering attention from many computer vision researchers since its introduction in 2015 [17]. YOLOv2, released in 2016, utilizes batch normalization, the Darkest-19 backbone, and anchor boxes to detect areas [18]. YOLOv3 was released in 2018 with the Darknet-53 backbone and a multiscale detection approach [19,20]. The addition of three backbone layers to the prediction layers means it can effectively detect objects of varying sizes. In April 2020, Alexey Bochkovsky introduced YOLOv4 with the spatial pyramid pooling (SPP) block and the CSPdarknet53 backbone. In June 2020, Glenn Jocher presented YOLOv5, which had backbone structures that differed from those of the previous versions [21–23]. In 2022, YOLOv6 and YOLOv7 were released around the same time. YOLOv6 adopts hardware-friendly designs for high-performance industrial applications, whereas VOLOv7 utilizes a novel bag-of-freebies approach and adopts an Extended-ELAN (E-ELAN) structure [24]. In 2023, YOLOv8, which achieved the current SOTA performance, was released. YOLOv8 optimized the VOLOv5 model structure and improved it with two duplicate headers on a single backbone. YOLOv8 is available through the GitHub repository, allowing individual researchers to develop the model with their own data (Figure 17) [25].

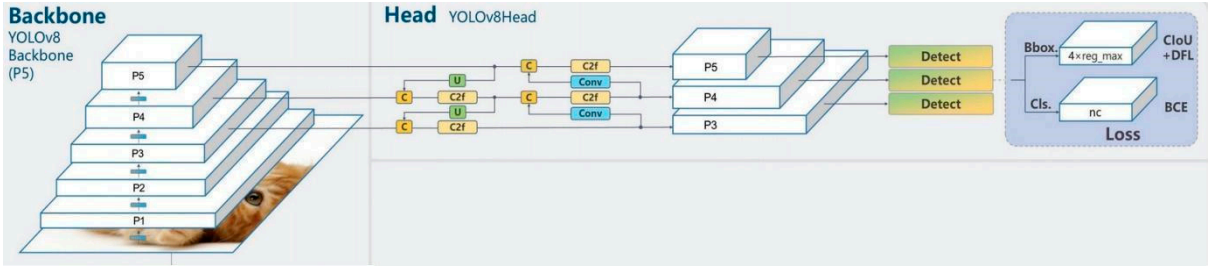


Figure 17. YOLOv8 architecture [26]. A figure depicting the structure of YOLOv8.

2.5. Segment Anything Model (SAM)

META's SAM is the strongest AI model used in computer vision. The model is used to segment data of varying types, including texts or images. Segmentation involves dividing objects in the input data into meaningful units. For instance, in image segmentation, an image is divided at the pixel level to determine which pixel belongs to which objects or backgrounds.

The SAM is based on the transformer architecture, which allows for the effective segmentation of varying data types. The model is trained with data properties using pre-trained weights, which can then be applied to new tasks. Moreover, being a zero-shot model, the model can segment objects on which it has not previously been trained (Figure 18).

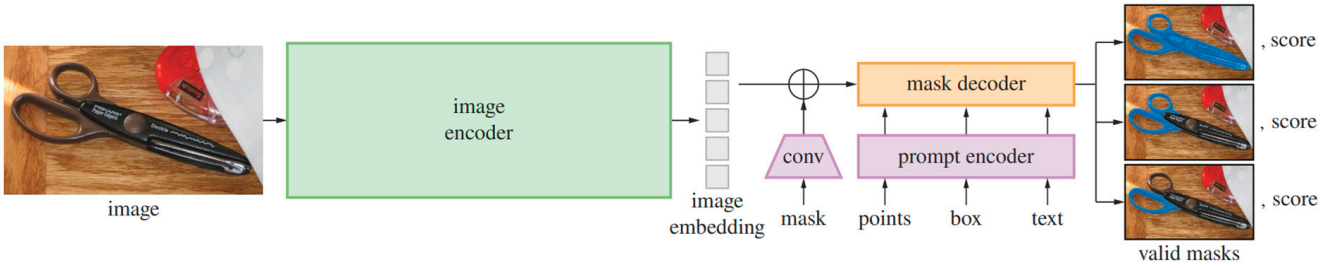


Figure 18. Segment Anything Model (SAM) overview. A heavyweight image encoder outputs an image embedding that can then be efficiently queried by a variety of input prompts to produce object masks at amortized real-time speed. For ambiguous prompts corresponding to more than one object, the SAM can output multiple valid masks and associated confidence scores [27].

2.6. Exif Tool

Exif is the image metadata format used in digital cameras. Exif was developed to embed varying types of information in image files taken with a camera, such as time. It has become prevalent due to the ubiquity of digital cameras and is considered the image metadata standard. Exif data are stored as parts of an image file and are preserved even when the image is altered using software that supports Exif data.

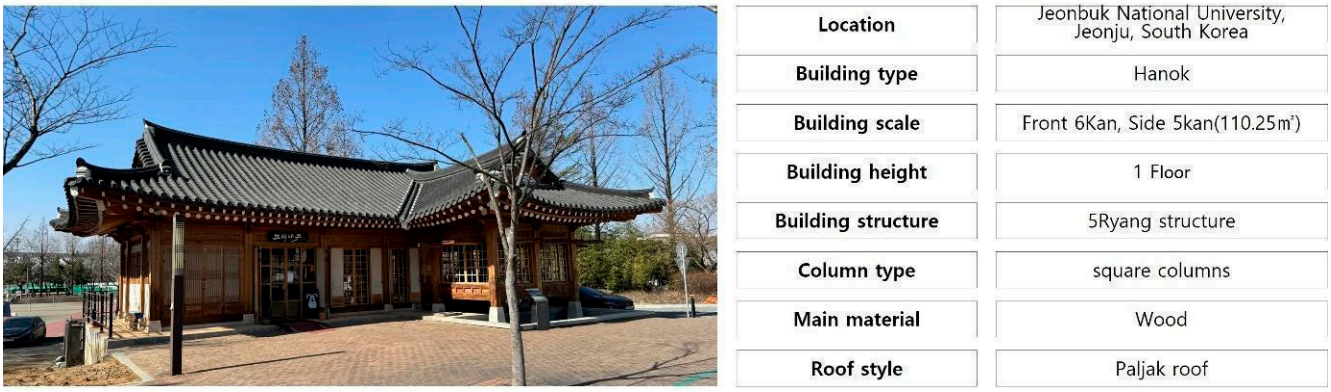
The Japan Electronic Industry Development Association (JEIDA) developed Exif version 2.1 in June 1998, and its latest 2.2 version was released in April 2002. While frequently used fields are standardized (e.g., dates, times, camera information, and camera settings), camera or mobile phone manufacturers may additionally extend data fields [28].

ExifTool is open-source software for reading, writing, and modifying Exif data. Its 1.0 version was released in November 2003, and after continuous updates, the latest version 12.77 was released in February 2024 [29].

3. Methodology

3.1. Research Subject and Methods

A Hanok, which has a general standard model, was selected as the research subject. The Hanok selected is a 5-Ryang structure constructed using conventional methods and wooden materials. Its roof was designed in the Paljak roof style, and its columns are square (Figure 19).



Location	Jeonbuk National University, Jeonju, South Korea
Building type	Hanok
Building scale	Front 6Kan, Side 5kan(110.25㎡)
Building height	1 Floor
Building structure	5Ryang structure
Column type	square columns
Main material	Wood
Roof style	Paljak roof

Figure 19. Hanok architecture under the subject of analysis. The Hanok under analysis is located at Jeonbuk National University in Jeonju, and it is currently used as a coffee shop.

Figure 20 shows the research experiment flow. Python 3.9.13 was used for the experiment. Each Hanok column was photographed with the iPhone 15 Pro Max. The research used a smartphone to extract Hanok deformation data, which are accessible to the general public. Because any tilts in photos can be misrecognized as leaning in buildings, ExifTool version 12.5 was used to extract the accelerometer values needed for horizontal correction.

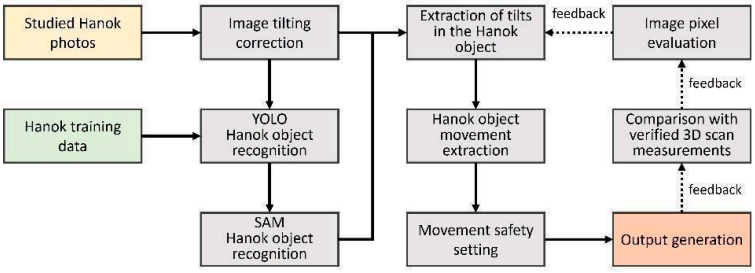


Figure 20. Experimental research flow. After the horizontal and vertical correction phases were performed for the Hanok photos, YOLOv8m was trained to recognize Hanok columns using Hanok training data. Column heights and centers were identified using the SAM algorithm to extract the leaning values of the columns. The column movements were visualized on a plane, and the final stability of the structure was determined from the set safety ranges. For data verification, the Hanok was measured with a 3D scanner used in actual Hanok measurements, and the scanned data values were compared. Data optimization was conducted by evaluating data loss by pixel resolution in photos.

To recognize the columns of the Hanok in the photos, AI data from the Korea Intelligent Information Society Agency were utilized. The YOLOv8m algorithm, trained with Hanok photos and training data, was used to recognize columns. The SAM_vit_h_4b8939 algorithm was used to precisely recognize accurate column boundaries that are necessary for calculating column heights and cross-sectional areas. After the Hanok column boundary recognition, image tilting correction values were added to derive the leaning values of the Hanok columns.

To visualize column movements on a plane, the movements were recorded, similar to the measurements of the leaning in the Hanok columns. The safety of the Hanok was assessed in stages based on changes in column movements, which allowed for the building's risk level to be visualized. The accuracy and reliability of the data were verified by comparing the values extracted from the studied Hanok photos and 3D scan measurements.

As error ranges in column leaning can broaden as a result of image pixel resolutions, photos, ranging from those with the lowest pixel count to high-definition quality, were evaluated to identify the range with minimal changes in leaning and determine the optimized image pixel resolutions.

The Hanok AI training dataset was provided by the Korea Intelligence Information Society Agency. The image dataset consists of 300,000 images from 600 traditional Hanoks, with labels annotated according to defined, specific categories and structures to train AI models. Additionally, the columns and the roof of the studied Hanok were recognized based on the trained data (Figure 21) [30].

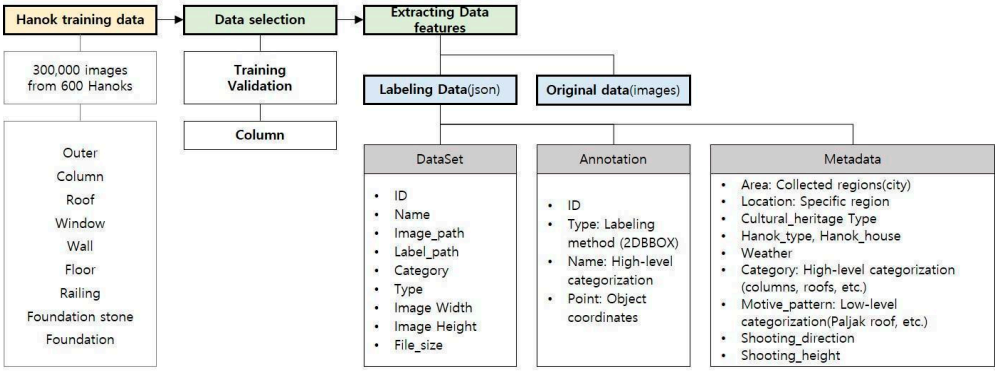


Figure 21. Components of training data. Hanok training data are categorized according to the elements in Hanok structures. Training and validation data for column elements needed for the study were selected and image feature datawere also extracted.

3.2. Image Calibration

The column center was photographed using the iPhone 15 Pro Max. Photo tilts needed to be corrected because any horizontal or vertical tilting in photographs could affect column leaning values. Photo tilt values were extracted with photo Exif metadata using ExifTool. The get_metadata (photo path) function was used to ensure that accelerometer values were present in the image properties, and the get_tags (photo path) function was used to derive final accelerometer values in the x, y, and z axes. The accelerometer values were then set to zero to correct tilts in photos (Figure 22).

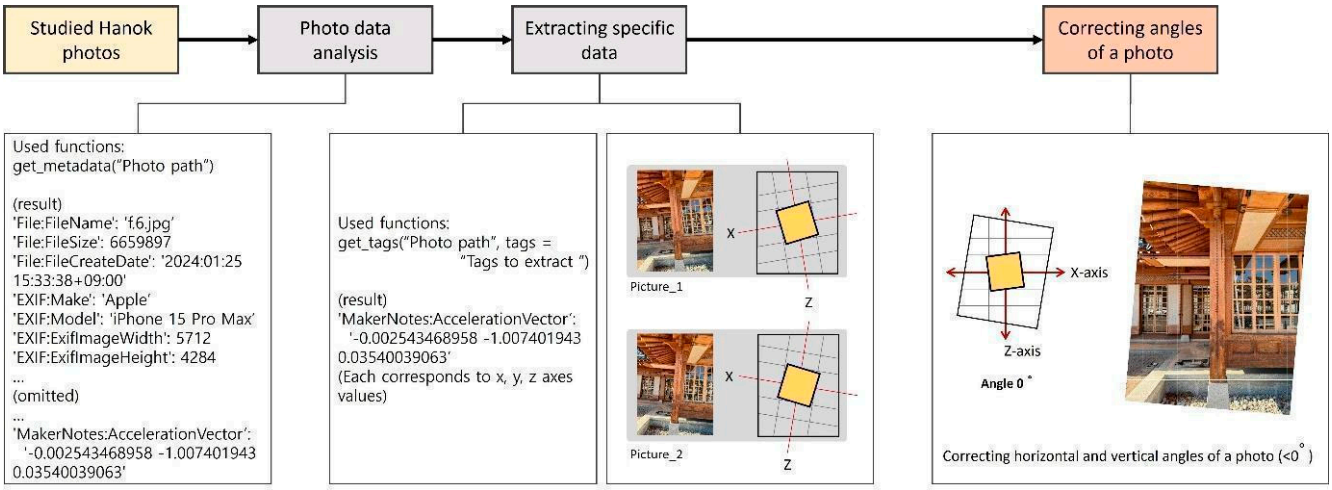


Figure 22. Image calibration process. Distortion in the object's (Hanok columns) inclination from camera tilts should be prevented. The accelerometer values in the photo were extracted from a device equipped with an accelerometer sensor. The sensor precision was up to 12 decimal places (0.000000000000). Only the accelerometer values needed for this study were extracted, and tilts in the studied Hanok photos were corrected.

3.3. YOLO- and SAM-Based Hanok Object Recognition

Various Hanok structural elements in the studied photos were captured. Because only the columns needed to be recognized, the YOLOv8 algorithm was used. Hanok training data were provided by the Korea Intelligent Information Society Agency, and it consisted of 300,000 images of 600 traditional Hanoks. The model for recognizing columns in the studied photos had to be developed. Models were developed through training, and hyperparameter setting was conducted to determine the conditional values for training. Because the hyperparameter setting can heavily influence the performance of the developed models, iterative tests were conducted until the model performance values were satisfactory. Upon evaluation, the trained model exhibited satisfactory performance: $mAP50 = 0.95917$ (95%), $mAP50-95 = 0.81116$ (81%), which implies that the columns in the studied Hanok were successfully recognized (Figure 23).

Segmentation was required to identify the centerline, height, and surface areas of sophisticated column objects. Therefore, a segmentation map was generated using ViT trained to segment each element in the studied Hanok photos during the image encoder phase. In the mask decoder phase, the segmentation map and prompts were cross-referenced to calculate the probability of each pixel, and images were restored to their original state through up-sampling. To segment only the desired Hanok column object, one of the point, box, or text elements should be utilized as an input. After testing all elements, a box was identified as the most appropriate for the research objectives.

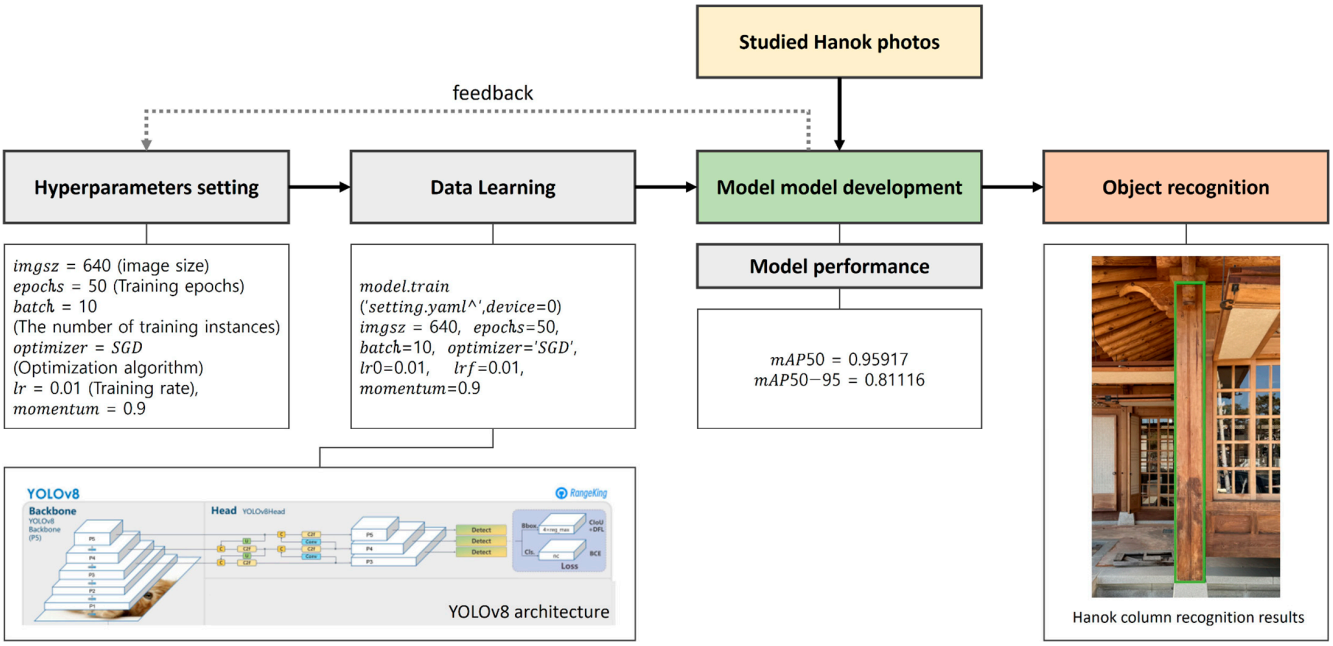


Figure 23. Hanok column object recognition using YOLOv8. Algorithm types and elements that affect training were selected during hyperparameter setting. The model was developed after data training, and hyperparameter setting and data training were iteratively conducted until satisfactory performance values were achieved. The studied Hanok photos were input into the developed model, and it successfully recognized Hanok column objects. The green rectangle reveals that columns in the studied Hanok were successfully recognized.

As the segmentation map and the prompts (values from the Yolov8) passed through the mask decoder, an effective mask for column areas was generated (Figure 24).

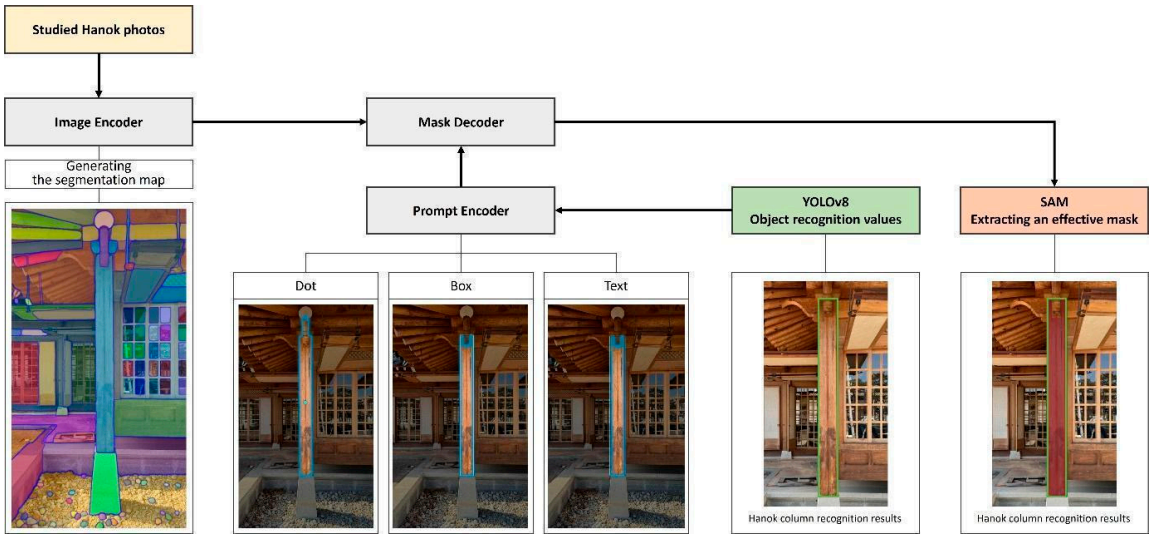


Figure 24. Extracting an effective mask for Hanok column objects using the SAM algorithm. YOLOv8 can recognize column objects but has limitations in quantification. Therefore, the actual area of a column was specifically represented by applying the SAM algorithm. The segmentation map in the image encoder phase is used to classify Hanok components based on colors. The choice elements in the prompt encoder phase include a point, a box, and text. Using the value derived from YOLOv8 (the green rectangle), effective mask values for columns (the brown area within the green line) were finally extracted.

3.4. Deriving Column Leaning and Movements of SAM Hanok

The YOLOv8 algorithm was used to recognize Hanok columns, and specific effective mask values for column areas were extracted using the SAM algorithm. To designate the center of a column, its upper-end and bottom-end parts need to be identified and connected. The centerpoint can be identified with an extracted output, as shown in Figure 24. At this stage, the actual cross-sectional area and height of the column need to be entered. The line vertical to the center of the column bottom can then be detected using the values obtained after correcting for photo tilt (Figure 25). Finally, the angle between the centerline and the vertical line of a column was calculated to derive the leaning value.

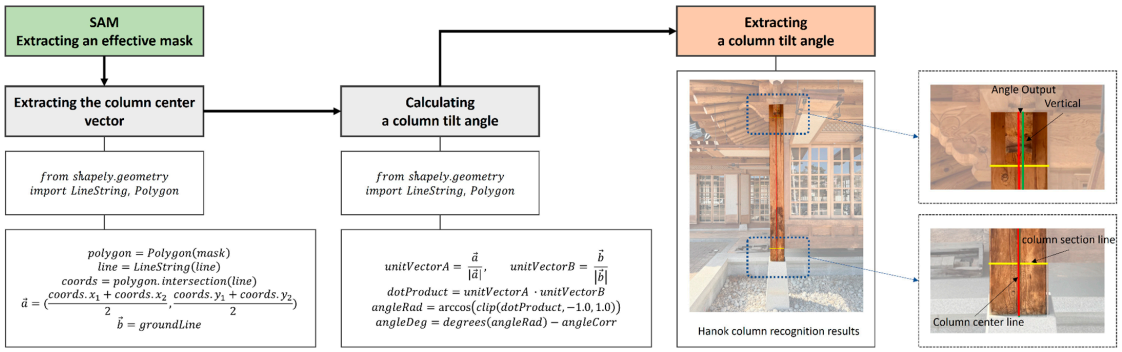


Figure 25. The computation of column leaning angle values. The function for extracting the column centerline vector and the ground perpendicular line vector. Column leaning values are obtained by computing the angle between the two lines. The yellow line indicates the cross-section (width) of a column, the red line is the column centerline, and the green line is the vertical line. The alignment of the red and green lines indicates that no leaning occurs in the column.

To derive column movements, at least two-way photos are needed. A one-way photo only yields left and right movements based on the photographer's perspective. Hanok columns are easy to measure as they are all externally exposed. Therefore, to assess their comprehensive movements, a column located at the corner of a structure was chosen as the subject. Two photographs were taken from the front and side of a column, and their movement directions and angles were computed. Integrating two datasets, the distances between the column centerline (red) and the vertical line (green) were computed with column heights. Finally, the cross-section center at the bottom of a column and the movement coordinates of the upper part of the column were overlapped to visualize and compute the movement directions and distances (Figure 26).

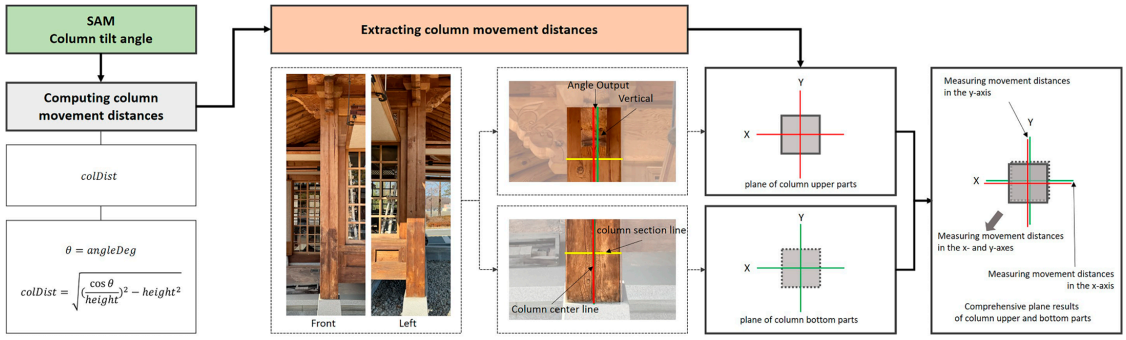


Figure 26. The computation of column movement directions and distances (plane). The function to calculate the column movement distance requires at least two photos taken from the front and side. Column leaning values from each of the two directions are computed, and the distance between the red and green lines is measured. The actual heights of the column are used. The final values for column movement directions and movements are extracted by overlapping the centers of the column's bottom and upper parts.

3.5. Setting the Safety Degree for Risk Detection

This study focused on column movements because the upper structures of a Hanok are all connected to columns. All the roof loads are transferred to the foundation along the upper parts of the column. If the movement directions of columns A and B are different, as shown in Figure 27, the horizontal components are separated from one another. Because steel is not used in Hanoks, the binding forces of connecting parts decrease with age, thus necessitating the use of metal to reinforce the structure. These parts are concealed by finishing materials and are not exposed externally. Therefore, column movement directions and distances can be used to predict structural stability.

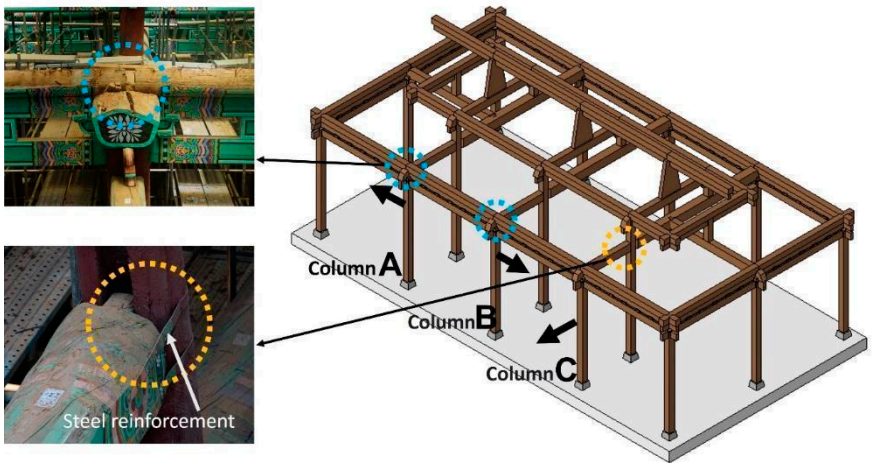


Figure 27. Hanok joint displacements against the column movement direction. Three-dimensional modeling visualizes the primary structural components of Hanoks. Some phenomena can occur from movements in columns A, B, and C.

Column movements were categorized into five phases: Phase 1: Good; Phase 2: Observation; Phase 3: Caution; Phase 4: Danger; and Phase 5: Very Dangerous. Phase 1 is characterized by mostly no movement in the column; column movements are detected in Phase 2; column movements are detected and may persist in Phase 3; the state of the Hanok structure in Phase 4 is considered dangerous, requiring immediate reinforcement; Phase 5 denotes a very severe state, and collapse is a possibility (Figures 28 and 29).

The column movements of government-managed cultural heritage Hanoks were measured and recorded, allowing for the structural deformation state to be inspected. The ranges in the column movement phases were categorized based on data extracted from prior research [31].

In the five phases of column movements are ranges that can be perceived with the naked eye and those that cannot. Visually detectable areas are already in a dangerous state, and extensive construction to dismantle and repair the building is required. Therefore, the most critical range to identify is that which cannot be detected with the naked eye during the progressive movements in columns. That range is the third phase, namely the caution stage. Hanok columns are designed to dynamically respond to varying forces. Specifically, they can move slightly, and it is important to detect whether the movement progresses in the same or different direction as the force. However, observing progress with the naked eye is nearly impossible. Inspections by experts using expensive equipment, such as 3D scanners, every month or year are also cost-prohibitive. Caution Phase 3 is important, as this is when unstable movement should be scrutinized by experts with 3D scanners. This phase is crucial for identifying causes early and addressing the key binding factors (Figure 30).

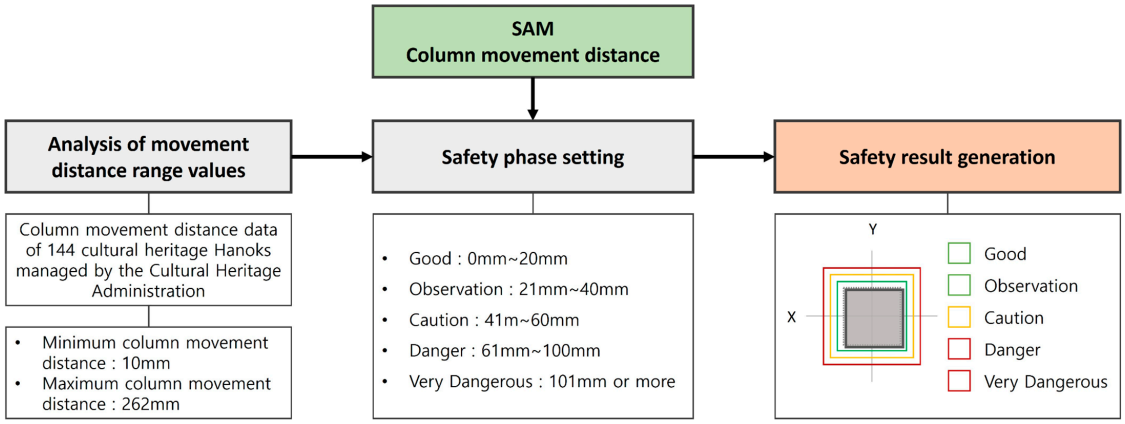


Figure 28. The application of the Safety Phase. Column movements of government-managed Hanok buildings are measured to range from 10 mm to 262 mm. Figures 3 and 9 show 262 mm of column movement, and the column has completely been disassembled for repair since 2016 due to structural risks. The distances of column movements were categorized into five phases, and the safety analysis results were finally derived.

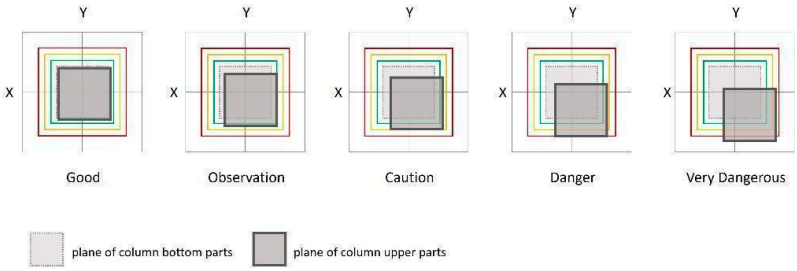


Figure 29. A 5-phase safety evaluation of column movements (a column plane). This is a plan view that visualizes the movements of the upper surface of the column. The figure illustrates the movement of the column's upper surface in the directions of the x and y axes. If the surface is within the green line, it is considered good; if it approaches or crosses the green line, it is under observation; if it crosses the green line and is between the green and the yellow boundary lines, it requires caution; if it crosses the yellow line, it is dangerous; and if it crosses the red line, it is considered to be in a very dangerous state.

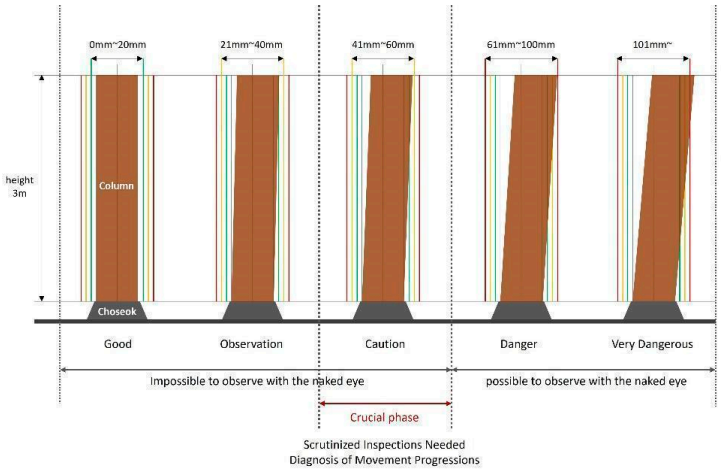


Figure 30. A 5-phase safety evaluation of column movements (column façade). The figure visualizes the movement of the upper part of a column. A foundation stone is placed on the ground, and a column is placed above it. Structural stability is represented by movements in the upper part of the column. The crucial range is undetectable with the naked eye and requires scrutinized measurements using a 3D scanner. The colored lines legend is the same as in Figure 29.

3.6. Image Measurement Verification with 3D Scanning

The studied structure was measured using a 3D scanner for Hanok building documentation and deformation measurements. The entire exterior of the subject structure was measured using a Scanstation C10 from Leica, and the scanned data were integrated using the Leica Cyclone 8.0 program (Figure 31).

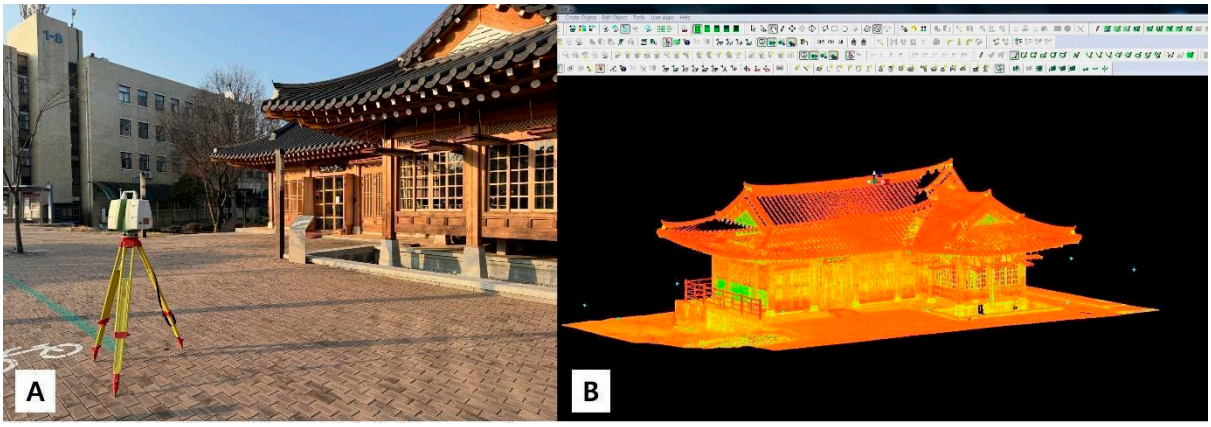


Figure 31. The 3D-scanned studied Hanok. Photo (**A**) shows the studied structure scanned using a 3D scanner. Photo (**B**) is the final result of integrating all the 3D-scanned data.

Leaning and movement distances derived from the scanned data of the studied subject were compared with those from smartphone photographs. The bottom and upper parts of the column were detected and linearly connected to set the column centerline in the scanned data, and its leaning values were measured. The leaning value obtained from the scan was 89.9757° whereas that from the photo was 89.9609°, which corresponded to a slight difference of 0.0148°. Considering that the maximum leaning value was 88.7513° in the 60 mm range of the caution phase in Figure 30, a difference of 0.0148° can be deemed negligible. The column movement distance was measured to be 1.2 mm in the scanned data and 1.93 mm in the photo, with a difference of 0.72 mm. This indicates that leaning can be adequately measured using photograph data (Figure 32).

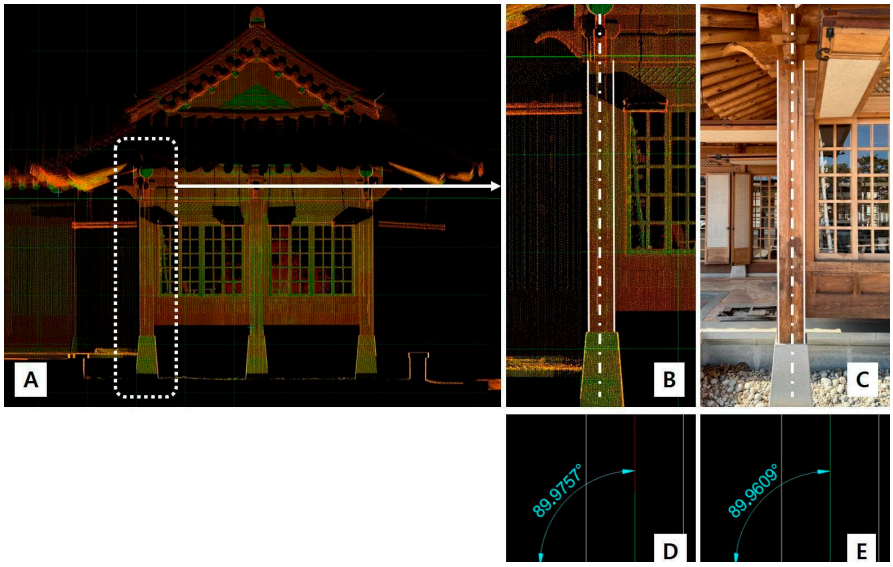


Figure 32. The column measurement results of the studied Hanok using a 3D scanner. (**A**) is the 3D-scanned result, which shows the front of the studied structure. (**B**) is a figure expanding the 3D-scanned part. (**C**) is a photo of a column taken from the same location as the scan data. (**D**) and (**E**) are the measured leaning values of (**B**) and (**C**), respectively.

3.7. Image Test

Error ranges can increase with photo resolution when measuring leaning values. As leaning extracted from photos is calculated without a professional measuring tool, the maximum error range was considered. The pixel positions in images subtly vary by resolution. The location of the central line of a column can differ when the column's boundary face changes. Therefore, image resolutions ranging from 100 × 133 to 4284 × 5712 were evaluated. Changes in leaning values by resolution were evaluated based on the 3D-scanned data. Accordingly, the leaning values were off by more than 1° at resolutions from 100 × 133 to 700 × 933. Stable leaning values were computed at a minimum resolution of 800 × 1066 (Figure 33).

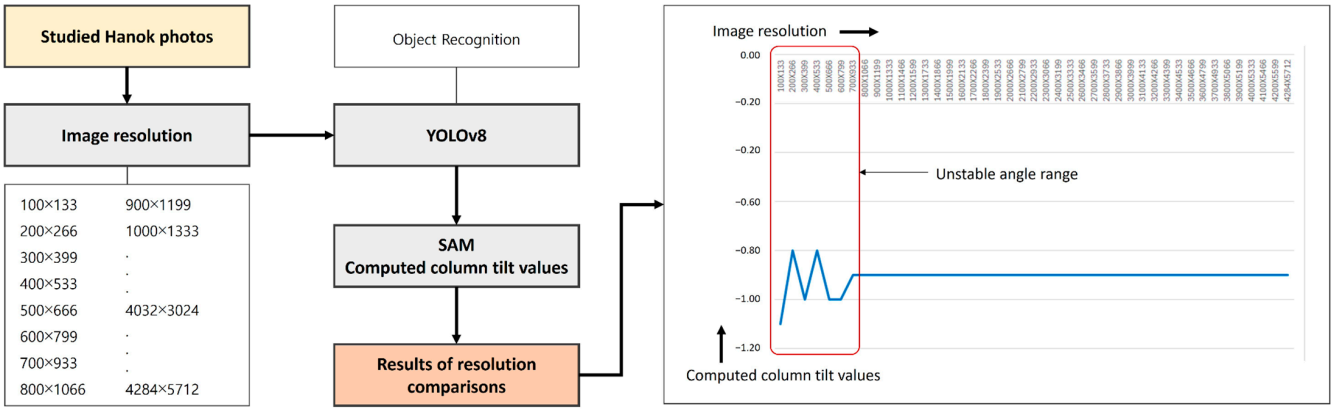


Figure 33. The evaluation results of the image resolution. Resolutions were compared by iterating the YOLOv8 and SAM stages using different resolutions in the photographs. In the graph, the area within the red rectangle exhibited unstable differences in leaning angles by resolution.

4. Conclusions

Hanok buildings are constructed by interlocking many horizontal and vertical structural components. The components are interlocked using various conventional fitting and connecting techniques. Traditional methods connect components using wood without using metal on joint parts. Although it is difficult to recognize any issues at the initial construction stage, the joint parts can weaken due to the aging of binding components.

In Hanoks, heavy loads from the roof are transferred through columns, increasing the overall structural binding force. However, the deteriorated performance of binding elements can increase the structural deformation rate. Precise structural diagnosis and subsequent measures can be performed when systems for monthly or annual measuring are readily available. However, there is an absence of a foundation for objectively quantifying data for assessment for Hanoks other than those managed by the government.

In this study, photos of Hanoks were taken using smartphones, which are easily accessible to nonexperts and can be used to diagnose deformations in Hanoks. Columns, the primary structural component of Hanoks, were investigated, and the YOLOv8 algorithm was successful in recognizing columns.

The performance of the column object recognition model was $mAP50 = 0.95917$ and $mAP50{-}95 = 0.81116$, and the final hyperparameters affecting the training model were set as *imgsz* = 800 (image size), *epochs* = 50 (the number of training), *batch* = 10 (the number of instances for each training), *optimizer* = *SGD* (optimization algorithm), *lr* = 0.01 (learning rate), and *momentum* = 0.9.

To derive quantitative data, a segmentation map was generated using the SAM algorithm, and precise column ranges were generated from the output values of YOLOv8. Vectors of the column center, heights, and cross-sectional areas were computed, which allowed for column leaning angles and movement distances to be computed. To validate the reliability of the output value, the Hanok under study was 3D-scanned, and the measured results were compared with the calculated values.

The results revealed that the margins of error were negligible: 0.0148° for the leaning value and 0.72 mm for the movement distance. This confirmed the reliability of the leaning and movement distance values extracted from the photos. Leaning changes in pixel resolution were evaluated to optimize these, and stable leaning values were extracted from a minimum resolution of 800 × 1066.

The safety range for column movements was determined based on actual measurement data from 144 government-managed Hanoks, and the safety was categorized into five phases (good, observation, caution, danger, and very dangerous). Deformations in the good, observation, and caution phases are hard to detect with the naked eye, whereas the danger and very dangerous phases are visually detectable. The critical range is where structural defects can be detected early but not with the naked eye.

Defects in Hanoks require objectively quantified data, not subjective. This study is expected to contribute to enhancing building stability and longevity through cause detection and intervention and minimizing damage from defects. A system for real-time measurement to derive output values by installing precise movement sensors on a primary Hanok structural component will be developed in the future. However, if a Hanok structural component suffers partial damage, only the damaged part is removed and replaced with a new piece manufactured to match it. This process can result in secondary defects, and it is crucial to understand which factors, either artificial or natural, had the most significant impact.

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