Conservation and Restoration of Chimi from Mireuksa Temple Site, Iksan

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Abstract

A *chimi* was a decorative architectural element placed at the highest point of a building’s roof that symbolized the dignity and authority of the ruling class. Unlike ordinary roof tiles, *chimi* were large and heavy and their production required advanced craftsmanship. However, as most *chimi* were made using clay, they have typically been excavated as numerous fragments of varying sizes and weights. This makes it difficult to determine their original form or identify the components of a single *chimi*, resulting in relatively few examples of complete restorations and limited related research.

This article focuses on a restoration study using selected fragments of *chimi* excavated from the Mireuksa Temple site in Iksan. The fragments feature relatively large remaining surface areas, making them suitable for the reconstruction. Most *chimi* pieces from the site are currently preserved as fragments, and even the larger pieces that had previously been restored require re-conservation treatment due to the deterioration of past restoration materials. The chosen *chimi* specimens were first disassembled, separating previously joined pieces and restoration materials. Subsequently, fragments deemed to be suitable for reconstruction were selected for each specimen. Using three-dimensional digital technologies, the relative positions of the fragments were estimated, and the missing parts were digitally reconstructed to ensure structural stability. Identifiable fragments were reassembled, and the missing parts were modeled and restored with 3D printing techniques.

Consequently, three *chimi* specimens from the Mireuksa Temple site were successfully restored to their presumed original forms. These restorations will contribute to future exhibitions and academic research.

1. Introduction

Various types of roof tiles were used in traditional Korean wooden architecture to prevent water leakage and fire. Among these is the *chimi*, a decorative tile that was installed only on the roofs of buildings associated with the ruling class, symbolizing hierarchy and serving as a talisman to ward off evil spirits and invite blessings.

According to the Buyeo National Research Institute of Cultural Heritage(Buyeo National Research Institute of Cultural Heritage, 2018), *chimi* were made using a range of materials, including stone, gold, gilt-bronze, and glass. However, most existing *chimi* in Korea are believed to have been made of clay. Due to the symmetrical structure of *chimi*, which were installed in pairs on either side of a roof, it is difficult to determine their orientation or estimate their exact placement. Furthermore, as they were made of clay, *chimi* are typically unearthed in numerous fragmented pieces, making complete restorations extremely challenging and rare.

The subject of this study is the Mireuksa Temple site in Iksan, a major temple and among the most important archaeological sites from the Baekje period. Since the beginning of excavations in 1974, approximately 900 *chimi* fragments have been unearthed (Figure 1). However, due to the varying forms and decorative patterns of these fragments, classifying them into individual specimens and accurately estimating their original positions has proven difficult. The complete restoration process, therefore, has required significant time and expert labor.

Recently, studies such as those by Jo et al. (Jo et al., 2019a) and Hwang et al. (Hwang et al., 2022) have drawn attention to the advantages of three-dimensional (3D) digital technologies, enabling flexible manipulation and processing of digital data within virtual environments to restore the original forms of cultural heritage. As part of the “Decorative Ridge-End Tiles (*chimi*) Excavated from the Mireuksa Temple Site: Documenting Their Production, Disuse, and Restoration” exhibition (Iksan National Museum, 2024), Iksan National Museum conducted a restoration project using 3D digital technology. The project focused on selecting *chimi* specimens excavated from the Mireuksa Temple site that either required re-restoration or retained a large remaining surface area, with the aim of estimating their original forms and restoring them to their complete shapes (Iksan National Museum, 2025). This study describes the process and results of the restoration of *chimi* pieces from the Mireuksa Temple site using 3D digital technologies.

Figure 1. Chimi fragments from Mireuksa temple site in the collection of the Iksan National Museum.

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2. Restoration of Cultural Heritage Using 3D Digital Technologies

According to Lee et al. (Lee et al., 2015), restoring the original form of cultural heritage and extending its lifespan often requires manual work that depends heavily on the experience and skills of conservation specialists. This process can be time-consuming and labor-intensive, based on the condition of the treated object. Therefore, a number of studies have been conducted in pottery and ceramic restoration, encompassing materials, techniques that are applicable to actual conservation, and scientific analysis. In recent years, restoration studies have actively pursued the use of 3D digital technologies.

Jo et al. (Jo et al., 2019b) noted that, unlike previous approaches conducted for evaluating the condition of cultural heritage, supporting conservation and restoration, or interpreting production techniques, 3D digital technologies enable the storage of heritage objects as 3D digital records. The data acquired can be freely modified and processed in virtual environments, allowing for the restoration of original forms and the production of replicas without direct contact with the heritage objects. These technologies are particularly valuable for their ability to closely replicate the shape, curvature, texture, and color of restoration targets. Furthermore, by selecting appropriate 3D printing methods and materials that are tailored to the characteristics of the object, the restored sections can be recreated in a way that minimizes visual or tactile differences from the original surface.

Research has also been conducted aiming to restore the original form of *chimi* using 3D digital technologies. For example, the *chimi* fragments recovered in 2016 from the Wangheungsa Temple site in Buyeo were modeled using 3D scanning by the Buyeo National Research Institute of Cultural Heritage (Buyeo National Research Institute of Cultural Heritage, 2017), which allowed for the restoration of their overall form. Meanwhile, in 2018, the Buyeo National Museum, owing to a study by Park et al. (Park et al., 2019), applied 3D scanning and computer numerical control technologies to produce a restored *chimi* having sufficient strength and structural stability. More recently, in 2022, the Buyeo National Museum successfully restored the original form of a *chimi* excavated from the Busosansaji site through research conducted by Hwang et al. (Hwang et al., 2022).

3. Research Methodology

The *chimi* associated with the Baekje Kingdom—one of the Three Kingdoms of Korea—are primarily found in Buyeo and Iksan. To date, only four *chimi* excavated from Baekje sites have been fully restored: two from the Busosansaji site and one each from the Wangheungsa Temple and the Mireuksa Temple sites.

In this study, Iksan National Museum selected three *chimi* specimens from its collection that either required re-restoration or were in relatively good condition. Additional fragments that were presumed to belong to the same *chimi* were selected following a visual inspection of surface color, firing traces, clay and sand grain composition, and decorative patterns. These fragments were evaluated for their potential of being joined or restored.

3.1 Research Subjects

3.1.1 Chimi Excavated from the Eastern Monastic Quarters: The remains of a building believed to have been monastic quarters were identified on the eastern side of the Mireuksa Temple site in Iksan. The *chimi* excavated from this area originally had two separate parts—upper and lower. However, as shown in Figure 2, only the lower portion remains. This *chimi* (Mireuk4941) was restored using plaster and provided an antiqued finish in 2018, and it was displayed at the Iksan National Museum until 2022.

Subsequently, fragments found near the excavation were identified as parts of the missing upper section, and some were considered to potentially fit with the remaining lower portion. This study was undertaken to re-evaluate the positions of these fragments with the use of 3D digital technologies to restore the complete original form of the *chimi*.

Figure 2. Lower Chimi excavated from the Eastern monastic quarters (Mireuk4941).

3.1.2 Chimi Excavated from the Pond Site: The pond site to the south of the Mireuksa Temple yielded the largest number of *chimi* fragments. However, most were small and made of soft clay, making it difficult to distinguish individual specimens. One *chimi* from the pond site (Mireuk9954), which was relatively well-preserved, had previously been restored using plaster and adhesive materials. As shown in Figure 3, these materials had deteriorated and required urgent re-conservation.

Figure 3. Chimi excavated from the Pond site (Mireuk9954).

Another *chimi* (Mireuk9953), presumed to be the matching counterpart of Mireuk9954, is shown in Figure 4. It has a similar form to Mireuk9954, and additional fragments that could indicate their mutual positions were identified, prompting an experimental restoration attempt. Mireuk9954 was dismantled by removing the remaining adhesive and plaster restoration, and fragments of Mireuk9953 considered likely to be joinable or restorable based on their excavation context were selected. All the selected fragments from the pond site were 3D scanned and modeled, following which their overall shape was reviewed using virtual reconstruction and scaled-down 3D-printed models. Missing parts were reproduced with 3D-printing compatible materials and were incorporated into the restoration process.

Figure 4. Chimi excavated from the Pond site (Mireuk9953).

3.2 Restoration Method

First, Mireuk4941 and Mireuk9953 were disassembled for individual 3D scanning. Mireuk9954, which had previously been successfully restored into a complete form, was digitally modeled to virtually estimate the positions of each fragment. Using the virtually reconstructed data, missing parts were reproduced with 3D printing and joined with the original fragments to recover the overall original form. The restoration was carried out in the following stages: disassembly and removal of foreign substances, 3D digital restoration, preliminary joining, reinforcement, final joining and restoration, and coloring.

3.2.1 Disassembly and Removal of Foreign Substances: For the Mireuk4941 *chimi*, the acrylic-painted areas were removed to reveal the underlying plaster restorations. The plaster portions were physically dismantled, and the joined fragments were separated, resulting in a total of 16 identifiable pieces. A similar method was used for Mireuk9954, resulting in the identification of more than 16 fragments, although well-preserved joined sections were not separated. Fragments presumed to belong to the Mireuk9953 *chimi* did not contain previous joins or restorations, and surface contaminants were removed.

Grade	Classification Criteria	4941		9954	9953
		Upper	Lower		
A	Joinable	-	17	18	4
B	Position estimable	8	1	3	3
C	Position undetermined	39		31	
Total (124 pieces)		65		59	

Table 1. Results of grading classification of Chimi fragments by individual specimen.

3.2.2 3D Scanning and Digital Restoration: The disassembled fragments, with additional pieces selected based on excavation context and appearance, were 3D scanned. Medium- and high-precision handheld scanners (Artec Leo, Artec 3D; and Space Spider, Artec 3D, respectively) were used to capture the detailed surface geometry. The medium-precision scanning utilized invisible laser light and was performed at approximately 22 frames per second in fieldwork. Meanwhile, the high-precision scanning used blue structured light at a rate of approximately 7.5 frames per second in indoor conditions. The scan data underwent the following processing steps: filtering, manual alignment and registration, global registration, and merging, resulting in a final polygon mesh and RGB texture-mapped models. From the acquired data, the *chimi* fragments applicable to the physical restoration process were selected for each object (Table 1). Fragments classified as Grades A and B—excluding Grade C, whose positions could not be determined—were virtually positioned drawing on previous successful full restorations, leading to the results of virtual restoration shown in Figure 5.

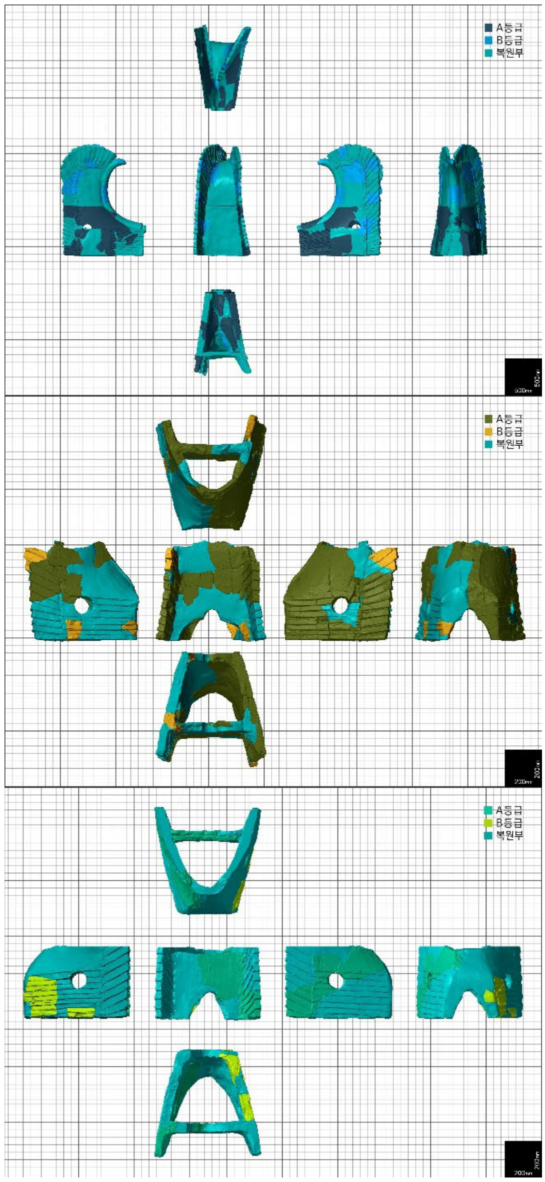

Figure 5. 3D Modeling results of the estimated position of Chimi(top: Mireuk4941, middle: Mireuk9954, bottom: Mireuk9953).

3.2.3 3D Printing: Before the restoration was applied to the actual artifacts, the scaled-down models were 3D printed to test for the possibility of joining fractured surfaces (Figure 6). To review the position of each *chimi* fragment, the reduced-scale models were 3D printed and physically tested for their fit. These printed materials were made from plastic filaments to reduce the weight burden for exhibition and transportation, in response to the heavy nature of *chimi*. Additionally, the interiors were printed in a lattice structure to ensure sufficient hardness to withstand the load after restoration.

Figure 6. 3D printed scale model of a Chimi(Mireuk9953).

3.2.4 Temporary Assembly: After the *chimi* fragments were dismantled, they were temporarily reassembled, and the order of joining of each fragment and 3D printed restoration part was reviewed before the actual assembly. The varying weights of the fragments made it difficult to fix them in place before curing the adhesive. Fragments of similar weight and size were grouped, and their joining positions and sequences were labelled (Figure 7). The parts of the 3D printed restoration, including missing areas, were printed in segmented sections for ease of assembly and were tested for their fit with the fragments' shapes and curvatures. When the contact surfaces between the **chimi** fragments and the 3D-printed parts did not fit precisely, or when the shape and curvature resulted in an awkward connection, the 3D-printed parts were reshaped to avoid forcing the restoration. Additionally, areas where the structure of the printed model made it difficult to attach the *chimi* fragments were re-divided to facilitate the bonding process.

Figure 7. Marking of joint positions and assembly order of the Chimi(Mireuk9954).

3.2.5 Strengthen: Epoxy resin is commonly used for joining heavy components such as *chimi*, due to its high mechanical strength, excellent durability, and low shrinkage upon curing, which provides strong adhesion at the bonding surfaces. However, a disadvantage of epoxy resin is its low reversibility, requiring physical methods for removal when disassembly is necessary. Therefore, it is recommended to first apply a reversible consolidant to the surfaces to be bonded, followed by the use of an epoxy resin for the actual joining process. After the hardness of the fragments of each specimen were checked, it was judged that the structure could be sufficiently maintained; therefore, reinforcement was only applied to the fractured surfaces requiring bonding. Paraloid B-72 10% (in acetone), known for its solubility and reversibility, was applied using a brush to strengthen the bonding surfaces, forming a sufficiently thick coating to allow easy disassembly at a later point if necessary.

3.2.6 Assembly and Restoration: Smaller fragments were joined to create pieces capable of bearing weight, and the *chimi* was assembled from bottom to top with epoxy resin (Devcon®). Gaps between the *chimi* fragments and the 3D printed parts were supported using epoxy putty (Quick Wood®) pieces to prevent movement before the adhesive cured. Meanwhile, internal and external cracks were filled with epoxy resin (CDK-520®), and the overall shape and surface curvature of the fragments were compared during restoration (Figure 8).

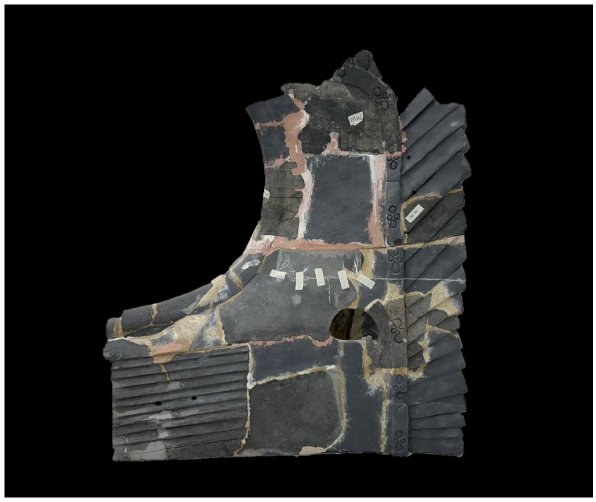

Figure 8. Upper and lower Chimi assembly and restoration process (Mireuk 4941).

3.2.7 Shaping and Coloring: The restored parts were shaped by sanding the surface to match the curvature. After a primer was applied on the areas to be painted, the base color was applied by airbrushing a mixture of acrylic paint and a dedicated medium. Features such as firing marks, cracks, inclusions, and glaze that were observed on the *chimi* surface were separately depicted using acrylic paint and brushes. The completed coloring result is shown in Figure 9. For the Mireuk4941 and Mireuk9953 *chimi*, the 3D printed surfaces and restored parts were fully colored; however, for the Mireuk9954 *chimi*, the left lower part was 3D printed, divided, and colored in sequential steps to allow for future exhibition and educational use.

Figure 9. Restoration results of Chimi(top: Mireuk4941, middle: Mireuk9954, bottom: Mireuk9953).

4. Conclusions

Although a large number of *chimi* fragments were uncovered during the full-scale excavations at Mireuksa Temple Site starting in 1974, they were stored as numerous broken pieces from different excavation areas, making it impossible to restore them as a single complete object. While the recovered fragments were classified based on their excavation locations, the nature of *chimi*, which are designed as symmetrical pairs with similar shapes on both sides, made it extremely time- and labor-intensive to identify and match individual fragments manually. Furthermore, the traditional restoration method of filling in missing parts with existing materials posed significant challenges, as it was difficult to modify already restored sections, making the overall recovery of the original form particularly problematic.

In this study, three *chimi* artifacts from Mireuksa Temple Site were selected for restoration to their original forms: Mireuk4941 and Mireuk9954, which required re-restoration as a result of the deterioration of materials used in previous restoration processes, and Mireuk9953, which was in the best preserved condition among the *chimi* fragments held by Iksan National Museum. For each *chimi*, previously restored parts were dismantled and fragments excavated from the same or adjacent sites were visually examined to select pieces that could be joined or whose positions could be estimated. The resulting shapes were reviewed and restored with 3D digital technology, following prior studies where complete *chimi* forms had successfully been restored and their characteristic features.

Considering the heavy weight of *chimi*, plastic filament–based 3D printed materials were used to reduce the burden of exhibition and transportation and prevent any damage owing to the deterioration of the restoration materials. This approach produced improved structural stability than the previous restorations, leading to a lighter overall weight and increased durability.

The restoration applied reversible joining methods and materials, allowing for easier partial disassembly and re-restoration upon the discovery of additional fragments with identifiable exact positions or patterns and forms of missing parts. During re-restoration, the virtual restoration data obtained through this study can be edited to remove the parts that are to be joined or restored and then 3D printed for use, enabling flexible partial disassembly and re-restoration that is closer to the original form.

The *chimi* restored through this study were exhibited in a special exhibition at Iksan National Museum in Figure 10 and are expected to serve as a valuable reference for future exhibitions and studies on roof tiles.

Figure 10. Utilization of the restored Chimi in the exhibition at the Iksan National Museum.

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