

The Gualchiere di Remole in Bagno a Ripoli (Firenze)

GIOVANNI PANCANI
University of Florence, Italy
giovanni.pancani@unifi.it

LORENZO MATTEOLI
University of Florence, Italy
lorenzo.matteoli@unifi.it

MATTEO BIGONGIARI
University of Florence, Italy
matteo.bigongiari@unifi.it

LUCA CHIAVACCI
University of Florence, Italy
luca.chiavacci@unifi.it

The Gualchiere di Remole represent a rare example of a late medieval industrial mill still standing in Italy. Built in 1327 by the Albizzi family, these structures were dedicated to the fulling of wool, a crucial process in Florentine textile manufacturing. Despite their historical and architectural significance, the Gualchiere are currently in an advanced state of decay. Declared a site of historical and artistic interest in 2013, the complex has undergone various interventions and transformations over the centuries but has never been subject to a structured restoration. Previous studies have focused on analyzing the mechanics of the mills and documenting the architectural conditions of the buildings. The research project began in 2009 with 3D laser scanner surveys to document the structure and understand the operation of the hydraulic fulling stocks. This initial phase utilized TLS instruments capable of producing a sufficiently complete and detailed point cloud, allowing for the mapping of both the interior and exterior and for assessing the state of conservation and functionality of the site. In 2024, a new photogrammetric survey using drones and high-resolution cameras updated the data on the condition of the mill and its hydrographic context. The combination of data collected in 2009 and 2024 enabled a direct comparison to evaluate the progression of degradation. This research provides a significant contribution to the knowledge and conservation of the Gualchiere di Remole, demonstrating the effectiveness of integrating 3D digital surveying techniques with modern digital photogrammetry (SfM) technologies. The comparison between laser scanning and photogrammetric surveys has produced a detailed picture of the mill's condition and its critical issues. The results may support future restoration and enhancement efforts, promoting the potential museumization and reuse of the complex for cultural and public purposes. The applied methodology has proven to be valuable for this type of industrial heritage, offering a replicable model for the preservation of medieval industrial sites.

Key Words: Conservation, Heritage, Survey, Remote Gualchiere, Photo modeling, Wool Art

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[480]

INTRODUCTION AND CONTEXT

The Gualchiere di Remole constitutes a rare monumental industrial complex dating back to the early 14th century, located in the municipality of Bagno a Ripoli, approximately 10 kilometers southeast of Florence. The site is situated on the left bank of the Arno River, directly opposite the settlements of Le Falle and Le Sieci. It is accessible via Provincial Road 34 'di Rosano,' which connects, beyond the town of Pontassieve, to the primary route linking Florence and Arezzo.

At present, the complex is in an advanced state of decay: the various building units are abandoned and severely deteriorated, and the spaces once housing machinery are unusable and nearly inaccessible due to collapses and structural instability.

Among the four major late-medieval fulling mills once built along the upper stretch of the Arno, the Gualchiere di Remole is the only example that has preserved its original architectural fabric. Comparable mills in Rovezzano, Girone, and Quintole have undergone substantial restoration and adaptive reuse, compromising their authenticity. These pre-industrial factories, dedicated to processing textile fibers, played a fundamental role in the production and distribution of cloth in 14th-century Florence. Today, the Gualchiere remains one of the very few surviving examples of a late-medieval industrial plant in Italy, providing unique evidence of the development of Florentine wool manufacturing.

The historical and cultural significance of the Gualchiere can only be fully appreciated within a broader national and international framework. Tuscany, for instance, preserves important analogies such as the Cavalciotto di Santa Lucia and the Prato canal network, a medieval hydraulic system that, in the 13th century, supplied nearly seventy mills and fulling plants, establishing Prato as a major textile center. The Gualchiera di Coiano, also in Prato, retains visible traces of its hydraulic system and machinery, offering tangible testimony to a resilient industrial past. Comparable examples can be found across Europe: the



FIGURE 1

A Recent Image of the Gualchiere di Remole, Taken from the Opposite Bank of the Arno River



Old Fulling Mill in Durham (United Kingdom), now a museum, and the National Wool Museum in Wales, both reflecting Britain's longstanding wool tradition; the French moulins à Foulon, of which some examples are still accessible; and the German Walkmühle in Wiesbaden, a former fulling mill successfully converted into a cultural venue.

Over the years, several proposals have been advanced for the rehabilitation of the Gualchiere and its hydraulic system, including the musealization of the complex along with other public-interest functions. However, none of these initiatives have been implemented. Only recently have new opportunities emerged for a publicly funded restoration project. Since 2013, the Gualchiere di Remole has been formally listed as a site of historical, artistic, and architectural significance under Italian national law no. 42/2004.

The first structured research project was launched in 2009 through collaboration between the author and Romano Nanni, then Director of the Museo Leonardiano di Vinci. The investigation focused on the mechanics of the water-powered machinery, particularly the vertical-axis waterwheels (*ritrecini*). A 3D laser scanner survey of the exterior façades was undertaken, and – thanks to the cooperation of the Municipality of Florence, the property owner – access was also granted to the interior spaces, including some semi-underground rooms that originally housed the waterwheels. Although only partial documentation was possible due to the poor state of conservation, the data collected provided sufficient insight into the functional layout of the mill.

More recently, an additional survey was conducted to analyze the water intake canal (*gora*) and the surrounding hydrographic and terri-

[482]

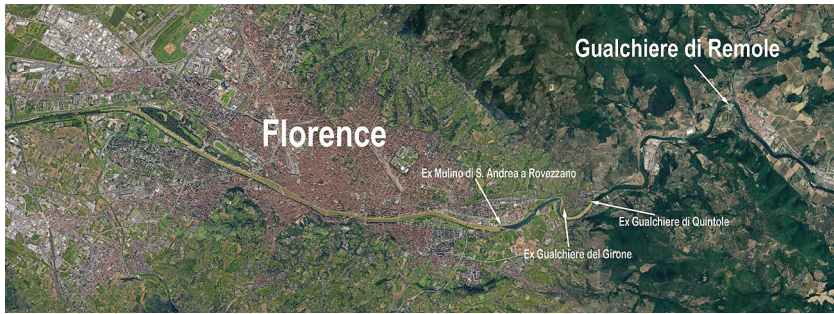


FIGURE 2 Florentine Plain Area

torial context, expanding the knowledge framework necessary for future conservation strategies.

HISTORICAL EVENTS AND OPERATION OF THE MILL

The Gualchiere di Remole complex was built in 1327 by the Florentine Albizzi family (Hoshino 1984), which during the same century – between 1322 and 1376 – managed to take control of all the most important mills similar to Remole, located upstream from the city of Florence (Rovezzano, Girone, and Quintole). This consolidation allowed the family to establish a dominant position within the Florentine wool industry.

As early as the 13th century, there are records of wool fabric manufacturing and finishing processes in the Florentine area. One of the first operations in the production cycle was ‘fulling’ (known as *gualcatura* or *gulchieratura*). Freshly woven cloth was soaked in alkaline or acidic solutions (including urine) and then compressed through pounding by machines powered by hydraulic energy (*gualchiere*). This process bonded the fibers together, making the fabric more resistant, compact, and even waterproof (Salvini 1982).

Historical records indicate that Florence had fulling mills powered by the current of the Arno River as early as the 13th century, mainly located within the urban stretch of the river. However, following the devastating flood of 1333 and the problems caused by the noise of the machines and the foul smells from urban hydraulic workshops, these mills were relocated upstream from the city, between Rovezzano and Pontassieve.

Today, the Gualchiere di Remole remains the only industrial complex from the 14th century still visible in its original architectural



form and location. Observing the complex, one perceives a structure resembling a castle set in the Florentine countryside (Carocci 1906; 1907), featuring two crenellated towers, an inner courtyard, and walls crowned with Guelph merlons. These fortifications, present since the original construction in 1326, were not intended for military defense [483] but rather to protect the production plant, warehouses, and residences from nighttime attacks by thieves seeking to steal valuable woolen cloth.

Alongside construction of the buildings, all necessary hydraulic works were carried out to ensure the water power required for the machinery. The first and most significant of these structures was the *pescaia*, an artificial river barrier about 200 meters long and 4 meters wide. It raised the water level at the required point and diverted it with sufficient flow to power the industrial facilities. A sluice regulated the water flow into the *gora*, a straight artificial canal approximately 400 meters long, 4 meters wide (Salvini 1982, 128–133), and 3 meters deep with a V-shaped cross-section. This channel conveyed the flow to the mill, powering the waterwheels, paddles, millstones, and hammers. Upon reaching the Gualchiere complex, the water flowed along the inner façade of the building and, through special openings (the *doccioni*), entered the lower part of the structure, activating the *rotoni* that transmitted motion to the machines on the upper floors.

The connection between the mill and the port on the opposite bank of the Arno was facilitated by a ferry, the *Nave ai Martelli*,¹ which allowed access to the main road leading to Pontassieve and Romagna, today known as the Tosco-Romagnola or Aretina-Forlivese. Most importantly, it enabled the transport of finished cloth to Florence via the river for additional refinement operations.

Originally, the mill was protected from potential intruders by a curtain wall with Guelph merlons and a rectangular layout. The two shorter sides of the walls (Carocci 1906; 1907) (about 50 centimeters thick) were destroyed in 1944 at the end of World War II, while the longer sides (approximately 80 meters) correspond to the outer façades of the still-existing buildings. These appear as two linear constructions facing each other at a distance of about 10 meters. The building overlooking the Arno River, surmounted by two towers, was designed from its incep-

¹ The remains of the structures of a port that allowed docking on the river are still visible today (Cosi 2002).

tion to house the fulling machinery, powered by the water that flowed through the lower floors. The other building was designated for workers' residences and storage facilities.

[484] In 1427, the Gualchiere di Remole housed fourteen fulling piles (machines used to full cloth) and a mill for grinding grain (*palmento*). The machines were installed underground, with the *rotone*, 'piles,' and *fol-loni* located beneath a wooden platform (*tavolato*). Above this platform were the 'shafts,' which alternately and repeatedly struck the cloth, thanks to the mechanism of the 'horizontal cylinder,' that lifted the shafts fitted with 'hammers' at their ends. The fabric, placed under the 'piles' and soaked in a hot acidic solution, was pounded by the hammers, enhancing its felting properties and making it more compact and durable.

After a period of decline linked to the crisis of the Florentine textile industry and, during the Medici era, to the diminished fortunes of the Albizzi family, the Gualchiere were acquired in 1541 by the Arte della Lana. This corporation continued the mill's production activities until its dissolution, ordered by Grand Duke Pietro Leopoldo of Lorraine in 1770, which led to the establishment of the Chamber of Commerce. Under the management of the Arte della Lana, the Gualchiere experienced a revival of production capacity, entrusted to the Del Soldato family, which remained in the complex until 1977. In 1610, some mills were converted into fulling machines, increasing the total number of fulling piles to 19.

A significant technological innovation was introduced in 1708 when the 19 traditional piles were replaced with three Dutch-style fulling mills. With the suppression of the corporation, ownership of the complex transferred for a decade to the Florence Chamber of Commerce, and in 1781 Grand Duke Pietro Leopoldo of Lorraine assigned it to the Cathedral of Santa Maria del Fiore, which managed it until 1812. During this period, a new Dutch-style fulling mill was constructed.

During Napoleonic rule, the Gualchiere di Remole returned to the management of the Florence Chamber of Commerce, which carried out the last expansion by constructing new buildings, as evidenced by cadastral maps from 1820–1830. The Chamber of Commerce maintained ownership until 1918, when the Municipality of Florence acquired the complex with the intention of transforming it into a hydro-electric power plant – an idea that was never realized. Under early municipal management, part of the Gualchiere complex was demolished to





[485]

FIGURE 3 2009 Survey

NOTES River-facing elevation, represented as a photoplane (obtained through image rectification calibrated on the laser scanner point cloud screenshots) and as a wireframe graphic of the masonry surfaces.

make way for a dye factory and lime-milling operation, while the mills continued functioning until 1977, when the Del Soldato family ceased activity. Milling operations continued until 1984, when the Cioni family also withdrew from production.

METHODOLOGY

The survey of the Gualchiere di Remole complex began in the spring of 2009 with the surveying of the external façades. For this initial survey session, a Leica Scan-Station2 laser scanner was used, an instrument that was already somewhat outdated and slow at the time, requiring operation through a PC connected directly to the device. Despite this, the scanner was highly reliable and capable of delivering excellent data in terms of both measurement accuracy and reflectance quality. It featured time-of-flight measurement technology, a declared range of 300 meters by the manufacturer, and an accuracy of 4 mm at 50 meters (based on FWHH) and 6 mm (based on Gaussian), with a scanning speed of up to 50,000 points per second. Furthermore, it was equipped with an integrated color camera with user-defined pixel resolution (low,

[486]



FIGURE 4 2009 Survey

NOTES Longitudinal section (top), transverse section (bottom left), and section along the *gora* at the entrance of the intake channel (bottom right). The sections clearly show the basement spaces housing the *ritrecini* and the ground-floor areas containing millstones and tools for the processing of manufactured textiles.

medium, high). A single image covered a field of view of $24^\circ \times 24^\circ$ with a maximum resolution of 1024×1024 pixels. The full dome of the scanner's working range spanned $360^\circ \times 270^\circ$ and was composed of 111 images that were automatically spatially rectified onto the point cloud. Using this instrument, only four external scans were carried out: two on the northwest façade (facing the river), one on the northeast façade, and one on the southeast façade to frame the internal courtyard of the complex (Bigongiari 2017).

A few weeks later, access to the interior of the factory was granted, allowing the use of a more modern and faster laser scanner, which could be controlled directly via its built-in display: the Leica 6000 (the twin of the Z+F IMAGER 5006). This instrument featured phase-difference measurement technology, a maximum range of 79 meters, a mean noise interval of 3.5 mm at 50 meters, and a scanning speed of up to 1,000,000 points per second.

With this device, all interior scans were conducted: ten on the



ground floor, where the mill machinery is located, and four in the basement, where the waterwheels are housed. The basement, in particular, still contained abundant sand deposits left by the flood of November 6, 1966.

The laser scanner survey project included 18 scans carried out with two different types of instruments. Although it was relatively small-scale project, it provided a firm reference point for understanding and documenting the condition of the building. The data was processed into 2D representations by digitizing referenced and scaled rasterized² images (ortho-images) of orthogonal views of the point cloud, including floor plans, sections, and elevations (Arrighetti et al. 2022). To represent the three façades of the Gualchiere di Remole, photoplanes were created in addition to wireframe restorations used for digitizing the stone ashlar. To achieve these results, photographic images were initially processed using planar photogrammetry software and subsequently calibrated against the ortho-images of the façade (Arrighetti et al. 2019). [487]

This initial 2009 survey provided adequate – albeit incomplete – documentation of the Remole factory. The material produced allowed for an initial assessment of the factory's operation and its state of conservation, highlighted through thematic maps identifying the primary causes of degradation (Borucka et al. 2023, 289–96).

In the spring of 2024, with the aim of further investigating the Gualchiere from a territorial perspective and to assess progression of degradation 15 years after the first survey, a new aerial photogrammetric survey using UAS (Unmanned Aerial System) was conducted, combined with a ground-based photographic survey.

For the aerial survey, two different drones with varying sizes and maneuverability were used. A drone equipped with a Hasselblad camera featuring a 1-inch sensor with 20 MP resolution, a 28 mm equivalent lens (35 mm format), adjustable aperture (f/2.8–f/11), and manual ISO sensitivity (100–3200) was used for wide-area and landscape shots. For closer shots near the dense vegetation surrounding the site, a more maneuverable DJI Mini 3 Pro drone was selected. This drone featured a vertically and horizontally adjustable camera with a 1/1.3" CMOS sen-

² The term rasterization refers to the discretization process of transforming a geometric primitive defined in a continuous 2D space into its discrete representation, consisting of a set of pixels of an output device (Scateni et al. 2005).

[488]

FIGURE 5

Wooden Paddle Wheel (*ritrecine*)

Such paddle wheels are powered by falling water and used in water mills to transmit rotational motion to the millstone



sor, 48 MP effective resolution, a 24 mm equivalent lens in the 35 mm format, and a fixed aperture of $f/1.7$.

With these two drones, a photogrammetric survey of the landscape surrounding the Gualchiere di Remole was carried out, with particular attention to the path of the *gora* (the artificial canal) from the weir along the Arno River to the factory. Additionally, the façades and roofs of the Gualchiere and the buildings belonging were surveyed. The drone photogrammetric survey was complemented by ground-based photographic imaging using a Sony A900 camera (24 MP CMOS sensor) paired with a Zeiss Vario-Sonnar T* 24–70 mm $f/2.8$ ZA SSM lens. The use of this equipment was planned based on specific parameters regarding distance and level of investigation: ‘of the first level, a third taking the second level from a great distance.’³

The photogrammetric point cloud was scaled, calibrated, and compared with the 2009 laser scanner point cloud to obtain an integrated and comparable survey.

³ To better reconstruct the surfaces of the pulpit, it was decided to make frames following three levels of investigation: a first general moving around the object at close distance, a second rotating around the elements (Pancani and Bigognari 2020; Pancani et al 2020).



ANALYSIS OF THE TERRITORIAL AND HYDROGRAPHIC
CONTEXT AND THE CONSERVATION STATUS
OF THE MONUMENT

The territorial context is a crucial factor in determining the location of the Gualchiere di Remole, as it is through this analysis that the factory's functioning can be understood (Parrinello et al. 2024). The landscape surrounding the complex is quite distinctive, consisting of an alluvial deposit wedge that is flat and rounded at its northernmost end, This natural formation forces the Arno River into a sharp bend, creating ideal conditions for construction of the artificial canal (*gora*) and the entire hydraulic system supplying water to the Gualchiere. Furthermore, the elevation difference created by the area's particular morphology facilitates the use of the Arno's water to power the factory. The water is drawn at the weir at approximately 68 meters above sea level and released back into the river at around 64 meters after traveling through the *gora*, which extends for about 400 meters.

[489]

Through the *gora*, water is directed into an upstream canal located above the factory, at a higher level than the waterwheels (*ritrecini*). Through conduits, the water is channeled with considerable pressure

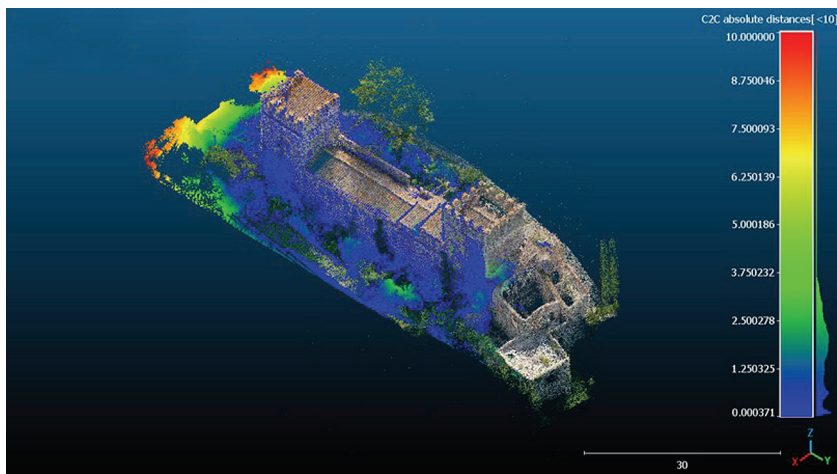


FIGURE 6 Survey Comparison

NOTES Image shows the comparison between the point cloud from the 2009 laser scanner survey and that from the 2024 photogrammetric survey. The comparative analysis highlighted morphological changes and degradation phenomena over time, with an average deviation between the two models of 0.052 meters.

[490]



FIGURE 7 Three-Dimensional Model Obtained from the Photogrammetric Survey of the Complex

NOTES The processing, derived from the acquisition and elaboration of digital images, allows high-detail representation of the architectural geometries and material characteristics of the mill, providing a reference base for metric analyses, diachronic studies, and future conservation operations.

into the basement of the factory, directly onto the ritrecini, causing them to rotate on a vertical axis. This motion is then transmitted to the machinery on the ground floor. After driving the ritrecini, the water is collected in a discharge canal, which returns it to the Arno River.

During site investigations, access was granted to three of the underground rooms, which contain a total of five ritrecini: two in each of the larger rooms and one in the smaller room. The ritrecini's wooden blades are individually mounted on a steel support connected to a vertical transmission shaft, which is also made of steel. On the first floor, several mills are located, each positioned above the axis of a ritrecine. These were used for grinding cereals and other materials. However, the machinery specifically used for fulling wool is no longer present in the accessible areas, likely having been replaced over time as the factory's production activities evolved.

The Gualchiere's production process used the Arno River not only as a power source but also as a transportation route for sending processed textiles to Florence. On the opposite bank of the river, the remains of a



small harbor are still visible, serving as evidence of this logistical function.

Despite limited access to the interiors, the survey allowed for an understanding of the functions of the buildings within the complex, including those not directly related to the factory. Residential buildings and warehouses, identifiable by their large entrance portals, overlook the internal courtyard of the fortified complex of Remole. As previously mentioned, an intake canal runs alongside the factory structure, featuring six small bridges and walkways providing access from the courtyard to the production rooms on the ground floor. [491]

Currently, the Remole Complex is in a precarious state of conservation, with parts of the roof having collapsed, putting the monument's survival at risk. The survey work carried out so far, although incomplete, provides a foundational knowledge base for initiating both restoration processes and initiatives aimed at increasing awareness of this valuable example of industrial archaeology. This project envisions organizing the collected data into additional 3D models created with parametric software, allowing for the integration of supplementary information to improve future conservation, restoration, and enhancement planning.

CONCLUSIONS

The Gualchiere di Remole represent an important testament to the Florentine wool industry of the late 14th century, a pre-industrial production complex that played a significant role in the economic and technological development of the city of Florence. The history of the mill, initially closely tied to the Albizzi family and its fortunes, and later linked to the of the Arte della Lana, demonstrates how the textile sector formed a cornerstone of the Florentine economy, which had successfully developed a sophisticated production system powered by hydraulic energy.

Despite their historical and architectural significance, the Gualchiere are currently in a troubling state of decay, with compromised structures and an uncertain future. Numerous restorations projects proposed over the years have not been implemented, leaving the complex in a condition of progressive abandonment. However, the site's inclusion on the list of assets of historical, artistic, and architectural interest offers a new opportunity to initiate conservation and enhancement initiatives.

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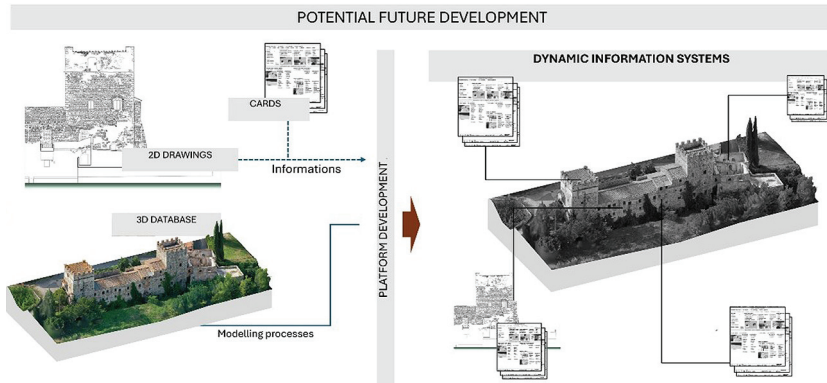


FIGURE 8 Evolution in Survey Data Management

NOTES From traditional models with separately managed information to a Dynamic Information System, which integrates three-dimensional data and historical information to support analysis, updates, and conservation of the heritage asset.

Recent surveys and studies conducted between 2009 and 2024 have yielded detailed documentation of the current state of the mill and its surrounding territorial and hydrographic context. The use of advanced technologies, such as laser scanning and aerial photogrammetry, has enabled an accurate mapping of the structures and an assessment of the degradation that has occurred over time. These data provide a valuable basis for future restoration work and for developing recovery strategies that respect heritage conservation principles while also considering potential cultural or museum-oriented adaptive uses.

The restoring the Gualchiere di Remole would not only preserve a site of significant historical value but also offer the community an opportunity to reclaim an important part of the city's industrial past. Achieving this goal will require a coordinated effort among institutions, cultural associations, and citizens to ensure a sustainable future for this extraordinary example of medieval industrial archaeology.

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[493]