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(Article begins on next page)

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Automated Recognition and Segmentation of Bricks Wall in Sicilian Monasteries

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Abstract. The oriental architecture present in the north-eastern cusp of Sicily is an expression of a mixed-race culture. This hybridization is evident in religious architecture. They have the typological imprint of Catholic churches with Latin cross plans and towered facades, but preserve Arabic traces in the structure of the domes and connections and exhibit Eastern Byzantine traditions in their masonry and rich decorations. The objective of this research is to automate the process of recognizing and segmenting bricks in wall structures to support the analysis of wall fabrics, a crucial task in archaeology and architectural restoration. Our approach processes a point cloud extracted from a facade to identify the wall texture. The results of segmentation can provide statistical information, documenting the average brick size, mortar thickness, identification of homogeneous areas, and recognition of masonry sections built with different bricks. Alongside the numerical and abstract information, it will be possible to identify the standard morphology of the brick, which also constitutes a sort of digital fingerprint of the church. The size of the bricks influences the geometry and layout of religious architecture. For example, the lateral facades are decorated with intertwined arches, entirely decorated with bricks. The spacing of the arches, the regularity and the overall morphology are determined by the size and arrangement of the bricks. The bricks placed on the beds in different ways (stretcher, rowlock stretchers, or heading) determine the repetition or alteration of the geometric-formal modules reiterated in the elevations.

Keywords: Artificial Intelligence, Python, Point Cloud Processing, Pattern Recognition, Architectural Restoration, Sicily.

1 Introduction

The oriental architecture present on the north-eastern cusp of Sicily is an expression of a mixed-race culture, the result of continuous hybridization among different peoples. In the early years of the new millennium, Sicily was crossed by Norman militias. Few well-armed men conquer the territory militarily.

The Normans, through multiple donations, try to strengthen the Christian faith and reinforce the religious communities present in the area. The religious architectures, built in a very short period, have the typological imprint of Catholic churches with Latin cross plans and towered facades; they preserve Arabic traces in the structure of the domes and connections, and exhibit Eastern Byzantine traditions in their masonry and rich decorations.

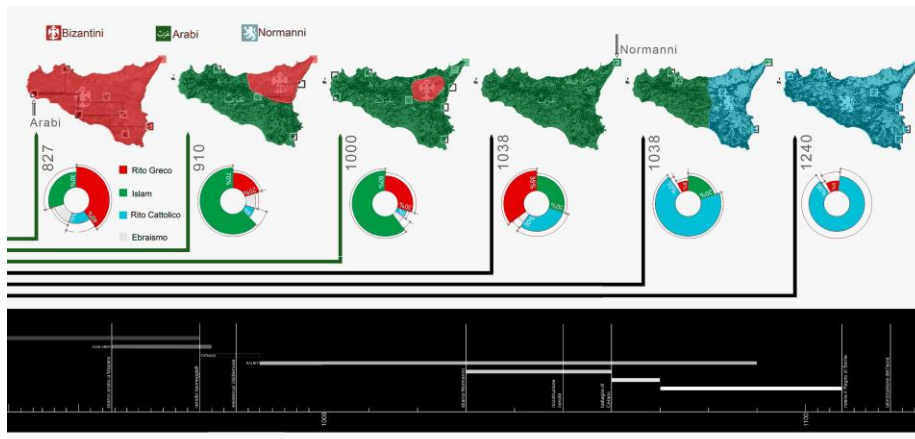


Fig. 1. Dominations in Sicily between 827 and 1240 (Photo: M. Arena).

Thanks to the numerous ‘Deeds of Donation’ of Roger II, three monasteries are established (S. Maria di Mili from 1092, S. Pietro e Paolo di Itala from 1092 and S. Pietro e Paolo di Agrò from 1117), whose architectures are similar characterized by dense and complex wall textures.

In north-eastern Sicily there have been many earthquakes that have damaged and destroyed the local architectural heritage. Many buildings contemporary with case studies have been lost.

The buildings we are talking about have suffered damage not only due to earthquakes but also caused by neglect and abandonment. In fact, these architectures are located in rural areas, far from historical centers. For many years they have been abandoned, used as shelters for animals, or sold to private owners. Paolo Orsi, Calandra, Borzi Salinas, and Kronig are some of the names that have studied a complex and intricate phenomenon such as that of the Italo-Greek churches in southern Italy [Calandra 2016]. The reconstruction of the dating is uncertain, due to the intertwining of populations and dominations, and the scarcity of sources. The peculiarity of these

architectures is concentrated in the wall structure. Despite the studies, it has not always been easy to distinguish the original elements from the reconstructed parts. The original wall sections from the reconstructed parts.

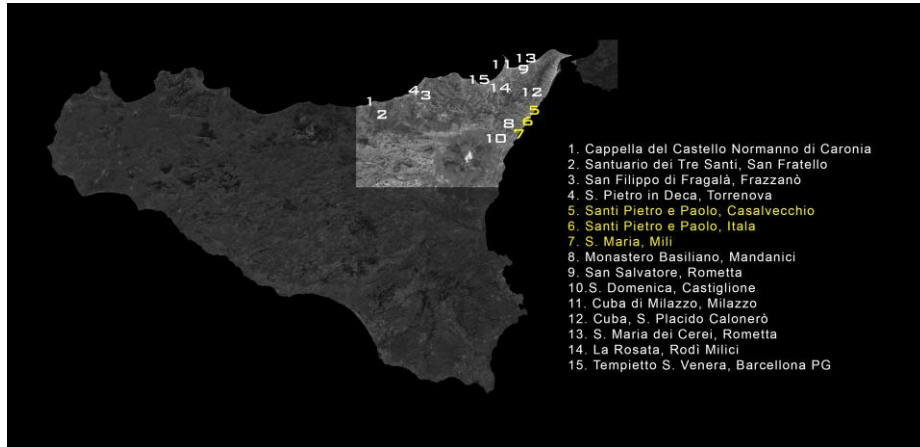


Fig. 2. Byzantine Monuments North-Eastern Sicily (Photo: M. Arena).

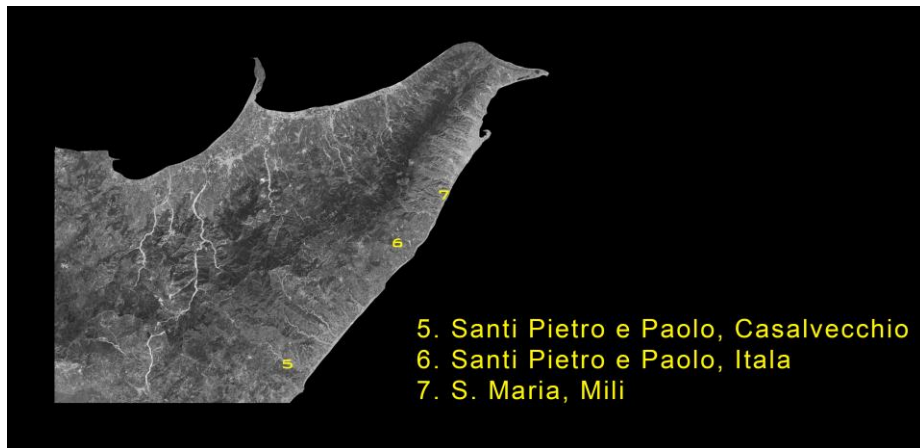


Fig. 3. Localization of the case study (Photo: M. Arena).

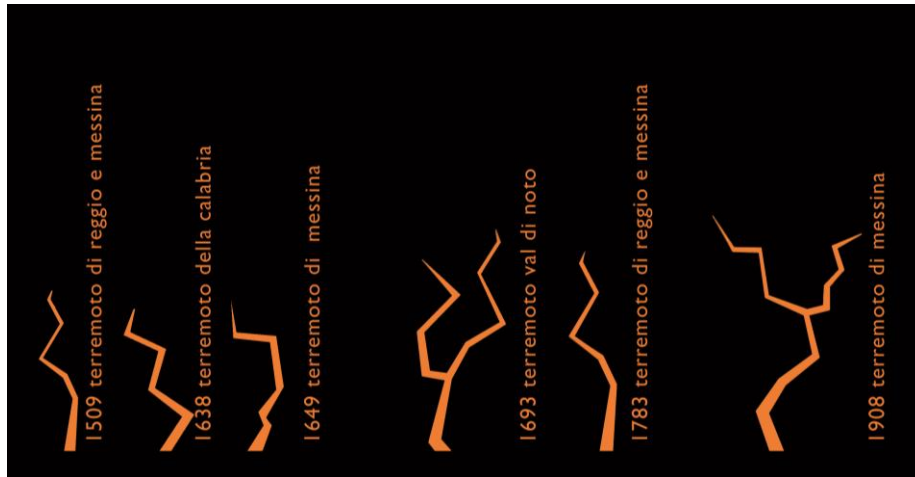


Fig. 4. Earthquake sequence in Eastern Sicily (Photo: M. Arena).

2 Case studies

The sacred architectures of the Eastern rite built in eastern Sicily and Calabria are often recognizable by the typology of the plan: some have a typically Byzantine layout, with a central or quincunx plan; others are distinguished by the presence of small extra domes or by the solutions adopted in the connections between the span and the vault, resolved with corner caps or trumpets. Still, others present a particular masonry device typical of Eastern craftsmen: the cloisonné which is an oriental technique where the stone ashlar are horizontally and vertically interspersed with bricks, it literally means ‘partitioned’. The masonry is characterized by the contemporary use of rough stone (lava pumice, white limestone, yellow sandstone, and Taormina stone) and bricks. The construction technique, the cloisonné, emphasizes the polychrome derived from the use of different materials and combines the arrangement of the bricks in stretcher, header, and rowlock. The horizontal recesses, made with hewn blocks of lava pumice, emphasize large bands of bricks arranged with herringbone patterns.

In this research, focused on the attempt to automatically recognize the origin and dating of the walls, it was decided to narrow the field to three architectures, in truth very similar, characterized by the same masonry equipment and the presence of decorations with crossed arches on the external walls. Inside, the churches have a more regular masonry: horizontal courses of bricks.

The three selected architectures are briefly illustrated below.

2.1 S. Maria, Mili

The church was built around 1090 by the Great Count Roger I of Sicily, who buried his son Giordano here, died in Syracuse in 1092.

The church and the annexed monastery are located near the Mili stream and, hidden by the slopes of the mountains, dominate the Strait of Messina and control the territory that was connected to them.

The church has reached us intact except for the lengthening of the hall, adapted it to the Latin cult, and the radical transformation of the main façade, located to the west. Inside it is still possible to clearly see the connection between the old walls and the new ones, built around the 15th century.

The naos, arranged like a small transept, does not exceed the size of the main nave and is marked internally by three small domes. The largest one rises on the bema and has the typical connection with angular headphones of clear Arab origin.

Externally the church is characterized by a lively play of intertwined arches (*interferentesi*) that also extend into the area of the apse. The arches are an integral part of the masonry, they stiffen it and, at the same time, create a spatial tension dictated by the pressing rhythm of the arches that intertwine on coplanar surfaces. The piers of the arches are made with a single brick arranged only flat.

The complexity of the masonry apparatus and the events that this building has undergone make it an ideal example for verifying and validating the procedures for recognizing and analysing masonry.

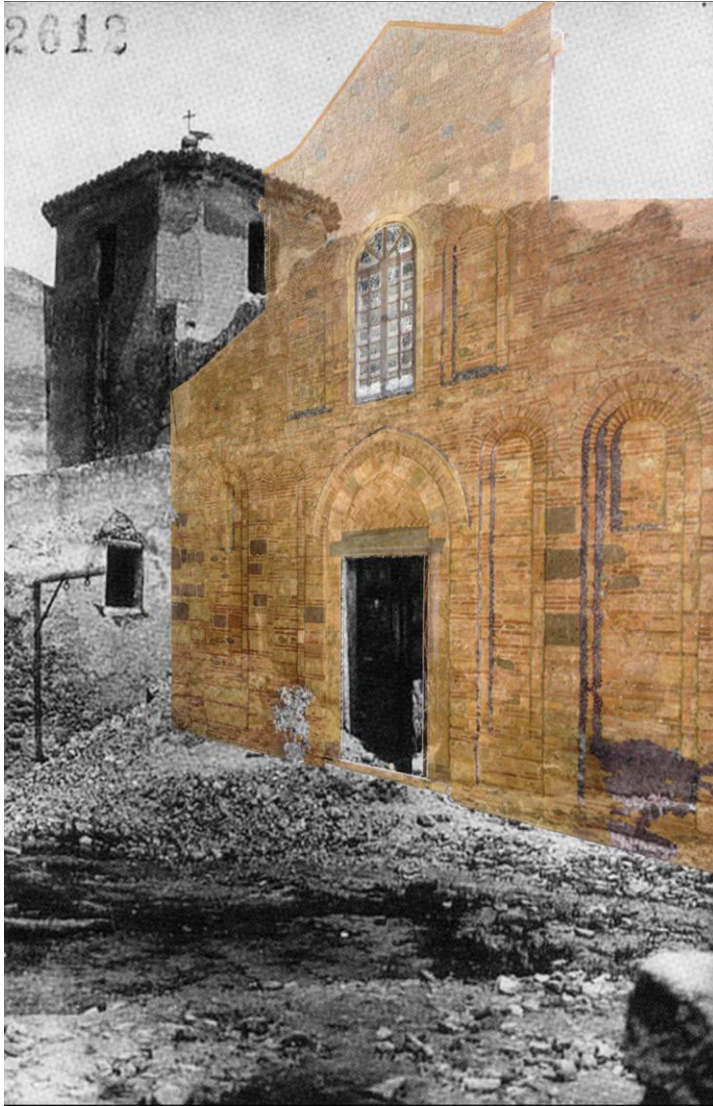


Fig. 5. State of conservation of the church of Saints Peter and Paul, Itala, 1925, overlapped with the current state (Editing: Marinella Arena).



Fig. 6. State of conservation of the church of Saints Peter and Paul, Casalvecchio, 1945, overlapped with the current state (Editing: Marinella Arena).

2.2 SS. Peter and Paul, Itàla

The church of Saints Peter and Paul is located on the slopes of Mount Scuderi, on the eastern side of the Peloritani, not far from the village of Itàla.

It was founded, together with the monastery of the same name, in 1092, thanks to a diploma of Count Roger (future king of Sicily) issued to Abbot Gerasimo.

The church has a basilica planimetry. The hall is divided into three naves with six columns (three on each side) with bell-shaped capitals on which brick and stone arch-

es are set. The coverage is flaky. The transept has the same width as the nave, so it does not emerge and has three apses.

The main façade is characterized, on the lower level, by a series of bow-shaped arches, at the center of which is the entrance portal. The portal has a double lava stone architrave and, between this and the first archivolt, there is a zigzag ornamental brick motif. The archivolts are interspersed with limestone inserts. At the top level, there is a series of blind arches, with a window in the middle. The side elevations are characterized by a continuous and uniform series of interwoven blind arches, with small alternately blind windows [Arena 2018].

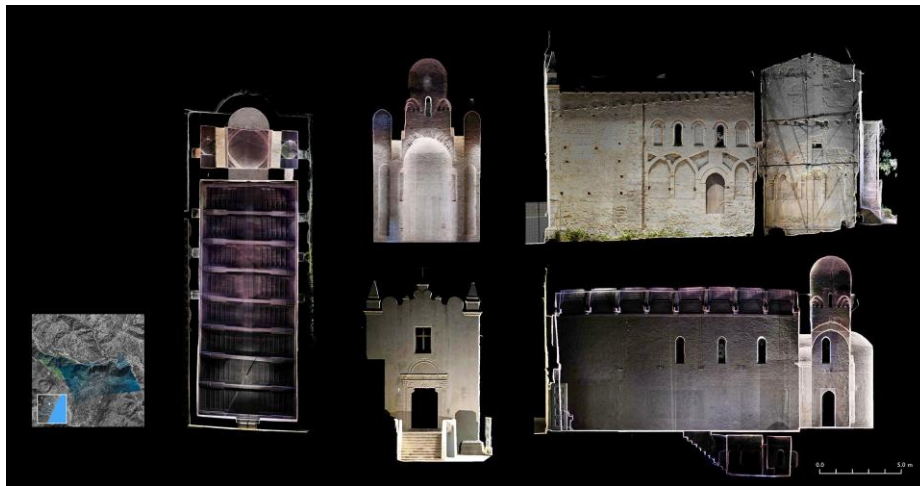


Fig. 7. S. Maria di Mili (Me). Instrumental survey conducted in May 2022 (Photo: M. Arena).



Fig. 8. Saints Peter and Paul, Itala (Me). Instrumental survey conducted in March 2017 (Photo: M. Arena).

The arches, intertwining, generate trilobed arches, a geometric pattern very common in Spain and on the southern shore of the Mediterranean, from Egypt to Morocco. A characteristic that makes the church exceptional is the polychromies of the materials, made up of bricks different in shape and firing, interspersed with stones of different shapes and nature [Arena 2018].

2.3 SS. Peter and Paul, Casalvecchio

The Basilica of Saints Peter and Paul, the last in chronological order to be built in this area, was built around 560, destroyed by the Arabs, and finally rebuilt in 1117.

The territory on which the Basilica lies is strongly characterized by the particular ground conditions that represent the ideal place for the construction of the small monastic settlements of the Byzantine era.

In fact, the monastery, for centuries, was the fulcrum of the economic and religious life of the area. In 1794, due to adverse environmental conditions, the Agrò stream was infected by the miasma produced by intensive flax cultivation, and the abbey seat of the monastery was transferred to Messina [Arena 2022].

3 A methodological premise

It is important to make a brief methodological premise. The three churches selected over the centuries have undergone, as we have seen, numerous renovations and reconstructions. In some cases, some sections of the walls have been demolished and rebuilt, in other cases the missing parts have been repaired. It seemed interesting to us to analyse as a first step two sections of the walls that are certainly original: the base parts and the portions of the wall in which the abutments of the arches fall [Tranchina 2023].

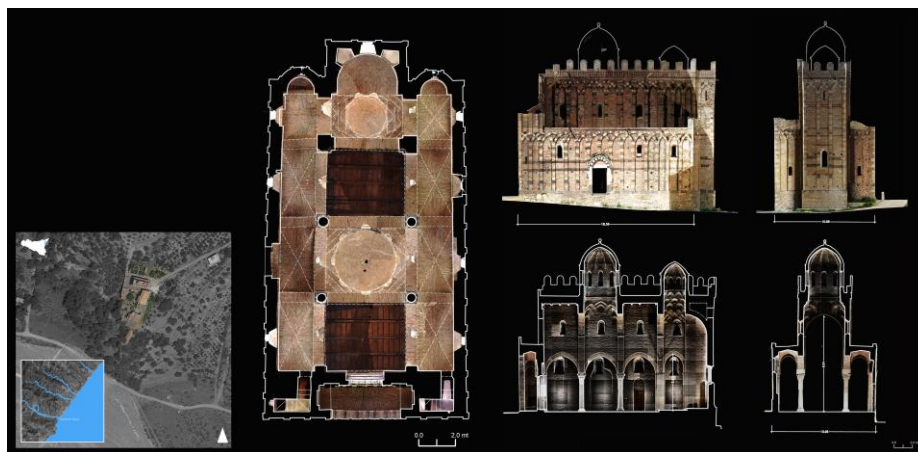


Fig. 9. Saints Peter and Paul, Casalvecchio (Me). Instrumental survey conducted in April 2018 (Photo: M. Arena).



Fig. 10. Three architectures compared: Saints Peter and Paul Casalvecchio, Saints Peter and Paul Itala, S. Maria di Mili (Photo: M. Arena).

The base parts are certainly the most authentic. For example, in the church of Saints Peter and Paul in Casalvecchio, the morphological analyses conducted on the geometry of the system have shown that the closer the horizontal section is to the impost plane, the more regular the layout is.

The abutments of the intertwined arches dictate the pace of the entire facade design. The arrangement of the bricks in the first course of the perimeter wall also determines the pace of the arches, which is not always constant. This is the case of the church of Saints Peter and Paul in Casalvecchio where the pitch of the arches is determined by the laying of the bricks on the impost plane. In some arches the bricks arranged flat are three in other arches there are two flat and one end. In this way the pitch of the arches is irregular. It is interesting to note how the size of the bricks is perfectly identifiable in the pilaster strips on which the blind arches rest. Here we do not find the mortar covering part of the brick. In this way, we can measure the brick in its entirety and define its measurements as 33x16x5 cm [Vandenabeele 2023].

4 Method

The objective of this research is to automate the process of recognizing and segmenting bricks in wall structures to support the analysis of wall fabrics, a crucial task in archaeology and architectural restoration.

To this end, we present a system based on Artificial Intelligence and implemented in Python, designed for the automatic identification of wall fabrics. Our technique has been tested on the three monasteries introduced in Section 2, for which instrumental surveys of the architectures were conducted using a Faro Focus 330 Laser Scanner. The scanner generates dense point-cloud data with ranging error $\pm 2\text{mm}$, complemented by RGB photographic images for color information. The acquired data are the input for the system.

Our approach processes the point cloud extracted from a facade to identify the wall texture. The system built for this purpose uses Python for data processing and OpenCV, a library of programming functions for computer vision tasks.

The method has been tuned (in terms of thresholds to be used) on some significant samples of bricks, which have been manually identified in the wall (the picture in the right corner of Fig. 11 shows an example of this selection).

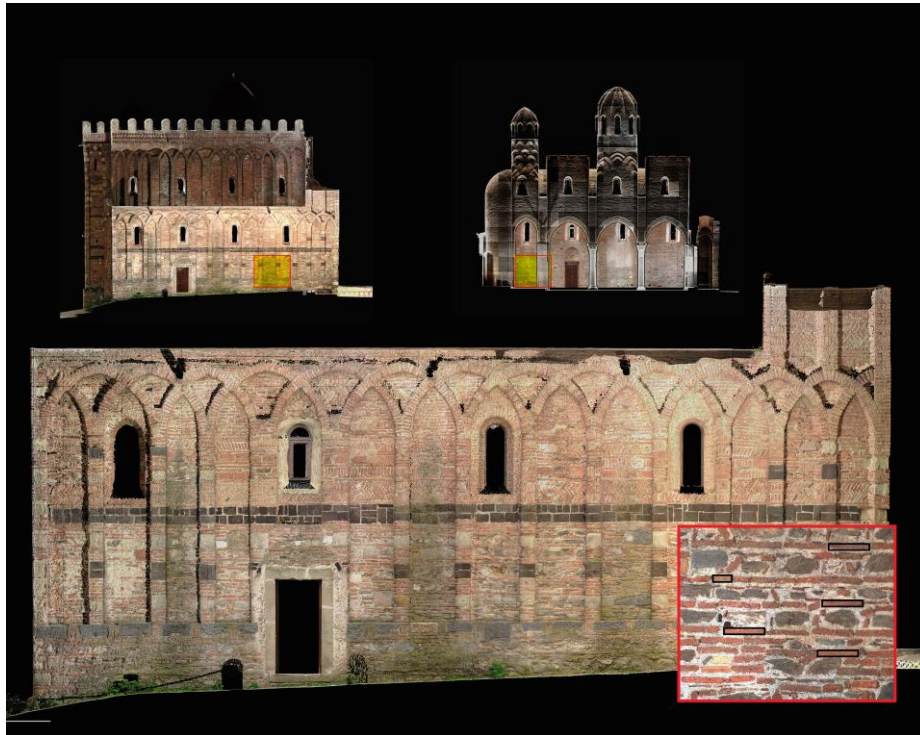


Fig. 11. Bricks manually identified in the wall and used to train the model (Photo: M. Arena).

The identification of bricks is done by carrying out the following steps.

1. Data points are pre-processed to take perspective and color distortions into account, aiming to improve the overall quality of the input for the next tasks of segmentation and object detection. Color distortions, possibly due to the variations of lighting conditions, are corrected using color normalization, en-

uring consistent color representation across different parts of the image. The image data are then converted to the HSV (Hue-Saturation-Value) color space. This conversion is important to separate chromatic content from intensity, which is particularly useful for color-based segmentation and object detection. Indeed, the hue channel is few sensitive to lighting changes strongly used for distinguishing objects based on color. Fig. 12 shows an example of the output obtained from one of the wall pieces after the pre-processing task.

2. One of the causes of bad segmentation is the noise in the image. To filter out the noise of the image and smooth it, we applied a 5x5 Gaussian filter kernel convolved with the image. This kernel size has been experimentally found to give good performances. Then, the first derivatives in various angles have been computed and pixels with a gradient value under a given threshold are filtered out. This threshold is specific for each case study and should be found from a human evaluation done on a representative part of the wall (we used the part reported in the right corner of Fig. 11). Fig. 13 shows several examples of contours found after this step.

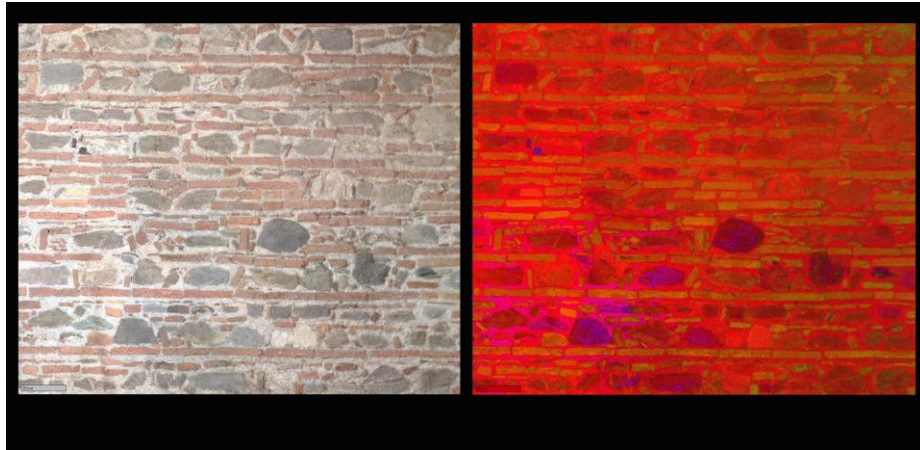


Fig. 12. Data point pre-processing (Photo: G. Lax).



Fig. 13. Results at the second processing step (Photo: G. Lax).

3. All the contours found in the previous step are analyzed to search for almost horizontal and vertical lines (looking for bricks and filtering differently directed objects). Found contours are rectified and measured in size. Contours delimiting areas too small (i.e., under a given threshold) are removed. Fig. 13 shows the result of the brick identification process, where different bricks are represented by colored rectangles, and colors are similar when bricks have similar areas. From a human check, we observed that most of the bricks are correctly detected and only a limited number of bricks have not been identified (two examples are marked by red arrows).



Fig. 13. Result of the segmentation (Photo: G. Lax).

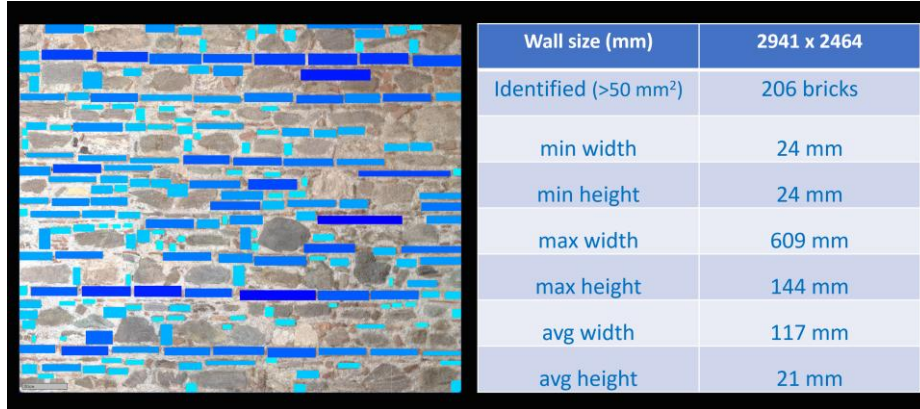


Fig. 14. Statistical information about bricks (Photo: G. Lax).

The support that this system can provide concerns various interconnected fields. For example, the results of segmentation can provide statistical information about bricks. In the table on the right of Fig. 14, we report this analysis done on a portion of a wall with a width of about 3 meters and a height of about 2,5 meters. We set the system to detect bricks with an area of at least 50 mm² and we found 206 bricks. Then, we measured the minimum, maximum, and average of their widths and heights. Such statistical information can be used for the identification of homogeneous areas and the recognition of masonry sections built with different bricks.

Alongside numerical and abstract information, some reflections related to the knowledge of places and architecture are possible. In the surrounding area of the monasteries, traces of kilns where the bricks used in construction were made, were found. Through this study, it will be possible to identify the standard morphology of brick, which also constitutes a sort of digital fingerprint of the church.

5 Conclusions

Sicily has historically been dominated by various peoples, including the Greeks, Romans, Byzantines, and Arabs. This succession of rulers has led to a profound cultural and architectural hybridization, particularly evident in the region's religious architecture. Sicilian churches often integrate architectural elements from different traditions, combining Latin cross plans and Romanesque facades with Arabic dome constructions and intricate Byzantine masonry decorations. This fusion of styles not only reflects the island's complex historical narrative but also results in unique architectural forms that embody the diverse cultural influences that have shaped Sicily over the centuries. The objective of this research is to study the effectiveness of an automated system for the recognition and segmentation of bricks in the masonry of Sicilian monasteries. By leveraging Artificial Intelligence and advanced image processing techniques implemented in Python and OpenCV, we designed a system that processes data points obtained through high-resolution laser scanning and enables the accurate

identification of brick patterns within wall structures. This segmentation allowed us to extract statistical characterizations of the bricks, including dimension and spatial distribution.

This system can contribute to the fields of archaeology and architectural restoration. The system facilitates the documentation of wall fabrics, offering detailed insights into brick morphology and masonry techniques. These details work as fingerprints of architectural elements and can help to distinguish original from later-modified constructions, thus supporting preservation and restoration. Additionally, the analysis of brick arrangements and dimensions can explain the historical construction practices and material usage unique to Eastern Sicilian monastic architecture and facilitate the recognition of the different phases of construction or restoration of churches. The size of the bricks influences the geometry and layout of these architectures. The lateral facades, for example, are decorated with intertwined arches, entirely decorated with bricks. The spacing of the arches, the regularity, and the overall morphology are determined by the size and arrangement of the bricks. The bricks placed on the beds in different ways (stretcher, rowlock stretchers, or heading) determine the repetition or alteration of the geometric-formal modules reiterated in the elevations.

Future work includes expanding the system's capabilities to handle more varied masonry types and improving its resilience to environmental factors such as erosion and damage. Building suitable machine learning models for more nuanced pattern recognition and extending the analysis to other architectural features can enhance the system's utility.

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References

1. Calandra, E.: Breve storia dell'architettura in Sicilia. Scicli, Edizioni di Storia e Studi Sociali (2016).
 2. Arena, M., Colistra, D.: The Church of Saints Peter and Paul in Itala (Messina). Survey, Graphic Analysis, Formal and Constructive Interpretation. In Pellegrini, G. (ed.) *De-Sign Environment Landscape City*. GUP, ed. Genova (2018).
 3. Arena, M.: The Imperfect Geometries of the Basilica S. Peter and Paul in Casalvecchio, Messina, *Nexus network journal* (24), 373–396 (2022).
 4. Tranchina, A.: *Monaci sullo Stretto. Architettura e greçità medievale tra Calabria e Sicilia*. Milano, Silana Editoriale (2023).
- Vandenabeele, L., Loverdos, D., Pfister M., Sarhosis V.: Deep Learning for the Segmentation of Large-Scale Surveys of Historic Masonry: A New Tool for Building Archaeology Applied at the Basilica of St Anthony in Padua. *International Journal of Architectural Heritage*, (2023). <https://www.tandfonline.com/doi/full/10.1080/15583058.2023.2260771> last accessed 2024/12/06.