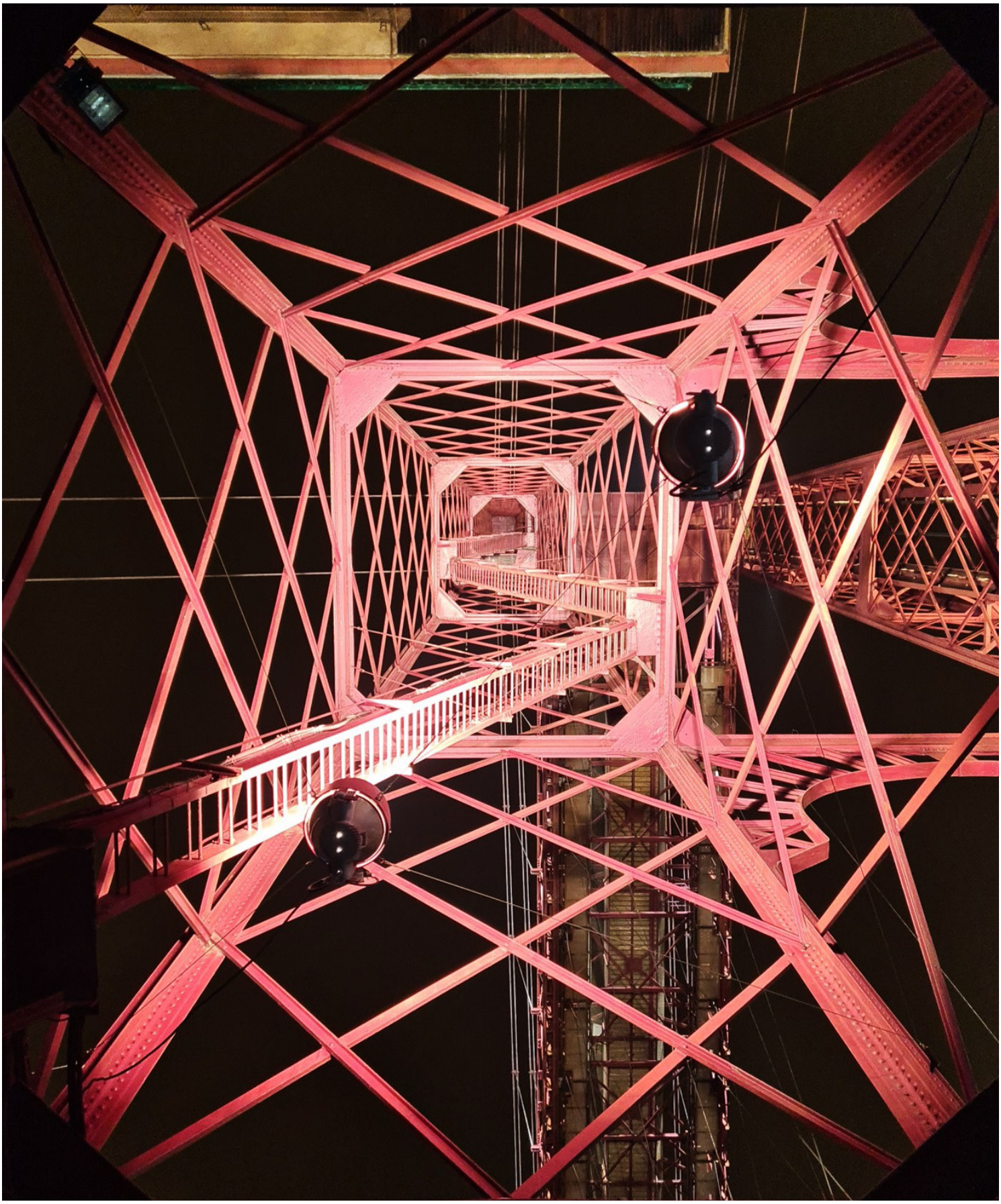

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THE MARBLE ENVELOPE OF THE *CASA DELLE ARMI* BY LUIGI MORETTI: DOCUMENTARY AND EXPERIMENTAL KNOWLEDGE FINALIZED TO DIGITAL MODELING

Marco Ferrero, Gabriella Arena, Adriana Ciardiello, Federica Rosso

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Abstract

The application of digital modeling for safeguarding the built heritage is a consolidated research field and carries substantial operational interest. The methodological aspects of this application are theoretically outlined but far from being commonly applied. In the perspective of delineating a more straightforward method for implementing these practices among the built heritage, modern Italian architectural production constitutes an ideal field of investigation, both for the significance of the built heritage and for the construction problems that characterize them. Indeed, in the case of stone cladding – which is typical of the Fascist period – the decay conditions and the peculiarity of the material make the investigation specific and paradigmatic of the implementation of the above-mentioned digital methodologies. The *Casa delle Armi* built heritage by Luigi Moretti in Rome, which has been the research subject of the Authors for years, features a marbled envelope detailed by the designer in every aspect, not only during the design phase but also during construction. This uniqueness makes the recovery of the envelope extremely challenging, as it should not alter its extremely complex nature, while today, the marble envelope is profoundly degraded by natural and anthropogenic factors. Digital modeling appears to be an optimal operational solution for guiding the recovery, but it presents many issues illustrated in this article and to which we have begun to give answers in this contribution. In particular, we delineate the knowledge of the case mentioned above study-built heritage, pursued through documentary analysis integrated by direct and instrumental observation on site.

Keywords

HBIM, Marble envelope, Luigi Moretti, Digital model.

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1. INTRODUCTION

Digital technologies present important development possibilities for the management of the built heritage. In particular, Building Information Modeling (BIM), conceived for the informed digitalization of the building process in the case of new constructions, is applied to the built heritage under the Heritage BIM (HBIM) definition, for which there are still open questions and challenges.

This contribution addresses these issues with respect to a key work of the Italian twentieth-century architecture: the *Casa delle Armi* by Luigi Moretti, built in the *Foro Mussolini* (now *Foro Italico*) located in Rome in the years 1933-1937. The marble cladding of this building is the first modern stone envelope built in the city and presents a peculiar technical solution – thin stone

slabs anchored with mortar and metal clamps to the wall-which was still experimental and highly innovative at the time and destined to be a reference for many works of that historical period. The early deterioration of the cladding is a consequence of the experimental nature of this technical solution and is common to similar applications characterizing modern architecture.

The recovery actions, aimed at conservation, maintenance, and improvement, can be supported by the digital methods, which are investigated together with their limits, in this contribution, with the aim of delineating a framework.

The framework is articulated into three main aspects:

- the application issue for the HBIM;
- the significance of the considered case study;
- the research method that is here applied and its results.

While HBIM was investigated in previous works [1], the research currently addresses the problem of survey data restitution on the BIM platform (*ScanToBIM*). On this aspect, there are significant results, as highlighted in [2], but the debate is open on the definition of "Level Of Knowledge" (LOK) [3], HBIM and database [4], and the semantics of modeling [5, 6]. Equally important for their potential development are also the tools related to virtual and augmented reality [7].

The stone facade of the *Casa delle Armi* by Moretti was examined. The realization of such a facade is paradigmatic of the definition phase of the modern architectural lexicon, deriving from the synthesis between stylistic innovation and technical experimentation. The desire to propose a solid reference for classicism in defining the language of the new Italian architecture, not extraneous to the ideological thrusts of the Regime that sought its cultural legitimacy in this reference, leads to having to solve utterly new construction problems to reconcile the needs of marble, fragile and heavy, with the lightness required by the structural cage, moreover elastic [8–11]. Inexperience and lack of knowledge of the properties of the materials were the conditions for such a quick deterioration experienced, as in other buildings, a few decades after its construction. Even the restoration interventions, which have occurred over time, have been conducted without the necessary skills. From a certain point on, they have also been vitiated by political prejudices that have drastically reduced attention to the specificities of the work, creating further and often irreversible damage [12].

This research represents the first phase of a broader program undertaken by the authors. The program aims to develop a protocol for modeling the modern architectural heritage in the context of sustainable informed management. The theoretical approach to the understanding of the heritage, which is the first preliminary phase of the modeling process, is here integrated with the geometric survey of the heritage and with the documentary research on the project and its construction features [13] through on-site observation through instrumental analysis and technical construction evaluation. However, the central problem is the definition of the criteria for digitizing the observations, as already stated previously, with respect to the construction of the HBIM model. The description and discussion of what has been done constitute the subject of this contribution, as detailed in the following paragraphs.

2. METHOD

2.1. IDENTIFICATION OF THE CASE STUDY

As already mentioned, the *Casa delle Armi* by Moretti is a significant case in the architecture of the Fascist period for many reasons. With respect to this specific research, the presence of one of the first thin stone claddings in marble – an architectural element destined to characterize the very image of the Regime, due to the references to Italic history and ancient Rome – is particularly relevant. The cladding is applied with a construction technique derived from that of traditional stone walls, but with a fundamental difference: indeed, the thickness of the marble slabs is reduced to a very few centimeters (3, in some cases even 2), thus entrusting the task of supporting the slabs to a layer of mortar integrated with metal anchors.

The limits and problems presented by this choice were the basis of the so-called "issue of marbles", which kept technicians and architects busy for a couple of decades [9, 13].

Due to this initial flaw and incorrect or badly executed interventions over time, the building is now severely degraded. The recovery appears very complex due to strong formal geometric constraints that do not allow any tolerance, considerably limiting the construction techniques applicable for consolidation. In addition, Moretti had designed every detail of the cladding, personally chosen each slab, and applied pictorial retouching on the texture of the marble veins, which makes the hypothesis of any replacement of the deteriorated slabs extremely critical.

In fact, the Architect conceived the cladding as a continuous envelope, a kind of unitary sculpture that encloses the building like an immutable skin. As a methodological premise, it should be specified that this very conception allows – specifically in this case – to analyze the problem of recovering this envelope, freeing it from considerations relating to the building as a whole. In other words, there are no alternatives to the stone envelope restoration, along with everything this entails in terms of the technical difficulty of the intervention.

If, on the one hand, the reduced thickness of the slabs leaves no room for rehabilitation of the material, on the other hand, the petrographic peculiarities of the marble make replacement difficult; moreover, every solution has to deal with the same causes of deterioration that degraded the current one in order not to incur in a repetition of the same problems. In this context, the digital approach appears to be the most suitable for formulating intervention scenarios that meet the many conflicting conditions and are also compatible with the economic resources available for recovery.

2.2. KNOWLEDGE AND DOCUMENTARY PHASE

Like all stone construction elements, the stone cladding requires a preliminary and detailed design of each construction element, specifically made in the factory. Not even Moretti, who was in the habit of making many changes during construction, could not escape this need. Indeed, by attributing importance to the stone envelope in the architectural definition of the building, he designed every single element in a well-known document, an accurate file concerning the entire supply of marble [14, 15].

By starting from this "abacus", the research examines the subsequent phases of the construction history: from the verification of the envelope's actual weaving to consolidation interventions and replacement of slabs, up to the survey of the current situation.

Another important aspect is the type of marble. There is no agreement on this and other information between the scientific literature and the documentary sources relating to the executive phase of the building construction. An in-depth doctoral research work, conducted by Vannucchi [16], has clarified many questions relating to the cladding, including the type of marble used (a veined *statuario* marble) and even the quarry of origin, without this being able to solve the problem of finding suitable material for possible replacements, as the current conditions of the basin are very different from those of the time.

The work is currently owned by CONI and is managed by Sport e Salute SpA, whose Office for Historical and Cultural Documentaries is part of the research group. The historical archives of the institution constitute a relevant documentary basis, integrated with the Ph.D. research mentioned earlier, conducted not only in the central and private archives but also in the field with interviews with the heirs of the Architect and of the Operators of the time.

Documentary knowledge, however, is not sufficient for the technical understanding, which is integrated with direct observations on the cladding and instrumental analyses. Those latter, still under development, provide additional information with non-destructive methods. In particular, the thermographic analysis promptly reveals the surface temperature differences of the stone slabs. These differences are an indication, on the one hand of the different reflections of the thermal radiation connected to the nature of the material and of the mineral intrusions that determine its veins; on the other hand, they indicate the degradation state of the surface and even the presence of the metallic supports, both the original anchors and the passing fixings inserted during the consolidation phase. Due to the different thermal properties, the thermography clearly shows the slabs replaced with others of different marble.

Finally, thermal fluxes crossing the envelope have been measured in order to verify the thermal transmit-

tance property of the façade. Measurements have been performed employing thermal flux meters, during suitable monitoring days, according to UNI EN ISO 6946:2008 regulation. The measurements were conducted during February for fifteen days. The investigated façade is the west one due to the possibility of applying the instrument on both the inner and outer face of the envelope and its peculiar architectural significance due to marble cladding.

2.3. DIGITAL STRUCTURING OF THE KNOWLEDGE

The digital organization of knowledge is the following phase, which preludes to the actual digitization by realizing the informed model. The modeling process must include the building's geometric shape, the construction techniques used, and the characteristics of the materials as a prerequisite for the definition of the intervention, the performance improvement, and the building management over time. For this purpose, the multidimensional structure typical of BIM (and HBIM) is used, which integrates the three geometric dimensions (3D) with aspects related to development over time (4D), costs (5D), management of the work in its life cycle (6D), up to the so-called facility management which defines the social, economic, and environmental sustainability of the building (7D). Despite the apparent descriptive breadth, the available practices do not match the actual modeling needs.

The major problem is represented by the limited possibilities of taking into account subsequent interventions over time, with differentiated and not predetermined phases, contrary to new buildings. In fact, consolidation and alteration interventions do not follow one another in a predictable way as in construction site operations; in addition, the model must allow for the integration of information with knowledge acquired in subsequent times. The problem was dealt with by Cernaro [17], who, in her doctoral research, developed the problem for a contemporary construction in Messina [18].

There are, however, other aspects that the digital model fails to take into account.

The facade of the *Casa delle Armi* is the result of a meticulous dimensional study, which Moretti made on the basis of the classical proportions and the Golden Section. The restitution of these relationships, implicit in the project drawings, fails in the reconstruction of the finished work and is further compromised in the current state. Obviously, the recovery intervention cannot ignore the compliance to these relations, but the digital model is not able to make them available for automatic processing aimed at supporting the decision-making process.

3. RESULTS AND DISCUSSION

3.1. THE DOCUMENTARY KNOWLEDGE OF THE BUILDING

Casa delle Armi is considered a masterpiece of the architect Luigi Walter Moretti. Also known as the *Accademia di Scherma* and in its first name as the *Casa Sperimentale Balilla*, it is located inside the sports complex of the *Foro Italico* in Rome, at the top of the southern section. Born as an advanced typological experiment, *Casa delle Armi* is considered the most modern of the buildings of the *Opera Nazionale Balilla*. Moretti creates a kind of architecture with a clear image and considerable functional complexity. At the end of Viale Angelico, its strategic location with connections to the historic city and San Pietro has allowed a representative designation.

As is well known, almost all the documents of the Moretti Archive have been lost.

The lack of textual materials in the archives obliges the research to reconstruct the design phases through a "circumstantial" process. This process has been followed by deepening the techniques used by the Architect according to the existing technologies during the construction period. The project started with an in-depth study by Moretti for the construction of a gym with a swimming pool; straddling the volume was a collector of curvilinear trends buried at 19 meters; in the second volume, which arose almost simultaneously, it was planned to include offices.

The two volumes appear independent and without connections from the archival findings. The connections appeared only in the second phase with pencil traces in the form of notes and only regarding the basement level. Subsequently, to these notes are added others where the two buildings appear connected with horizontal paths at two levels, and the building assumes the "L" arrangement, divided internally by different elevations joined by

a third volume in the shape of an ellipse, that distributes and welcomes the two wings. The construction process is testified by the executive drawings, representing only the initial phase: many decisions were taken during the works, and only some were codified in notes or sketches. The dates of the documentation are various. In the archives are kept three photos, dated April 4, 1934, of the building being completed and two photos by Alinari, dated 1935, which, as an archival location, are inserted in the photo pool of 1937. Although among the first official shots, an event appears – the first official, the *Exhibition of Sport* set up in the body of the Library and the *Exhibition of the Houses of Balilla* set up in the body of the weapons room – the first official date is linked to a visit by Benito Mussolini on October 28, 1936.

In 1937, the building appeared to be divided architecturally into two parallelepiped volumes, namely the Library (and its ancillary spaces for meetings and room for the Museum) and the *Sala della Scherma* (and its ancillary spaces, such as the services). Before this final functional subdivision, the building was first intended as *Casa Sperimentale* ("experimental house"), then as a gym, then as the swimming pool, and all of these functional variations are testified by only one drawing. According to the saying of the time, the combination of the Library and the *Sala della Scherma* is seen by some historians as a recall of the "book and musket". In the spring of 1937, when the Balilla Statue by Bellini was placed, the project of the *Casa delle Armi* was considered concluded. During the same year, in August, the famous article by Plinio Marconi was published in the magazine *Architettura* [19], which described the geometry, functions, and characteristics of the *Casa delle Armi*. Therefore, in the document on the marble envelope of the building, the 1937 date will be used as a reference for the conclusion of the construction.

The area of the *Foro Italico*, with the construction of the Morettian building, takes on a new trend compared to the rest of the existing buildings; its tendency is almost abstract and metaphysical because it is characterized by the rigorous use of white tones woven between classicism and baroque. The *Casa delle Armi*, "dressed in white", also imposed its image on the *Foresterie Sud* by Enrico Del Debbio, who had to modify his work painted in red – called Pompeian – both in volume, raising a floor the artifact, and in style and functionality, covering the building with white marble. The white imposed by Moretti was not to be absolute. However, several whites with similar facets were sought and created by the Architect with detail, craftsmanship, and careful technique, as well as with a great work of research of the material and its relative technique aimed to propose the architectural language of the *Foro Italico* as "modern".

For the *Casa delle Armi*, Moretti opted, differently from what he did for previous works for example in the Monoliths of the Piazzale dell'Impero, for marble with fewer veins as possible. Although the documents found as evidence are not many, the choice of the cladding material of the architecture is clear, a Moretti choose slightly veined white and bright Carrara marble, called *lunense*. In the archival documents, there are a series of executive drawings relating to the marble cladding blocks: a sequence signed by Moretti and qualified as "architectural orders". The same care taken in the paper restitution of the slabs characterizing the facades was carried out in the immediate outdoor space of the building, both for the outdoor paving and for the decorative pool.

Moretti's approach is a methodological and design approach that connects the "rediscovery" of the rules of antiquity with the projection forward allowed by scientific-technological innovation, of which the cladding is one of the most striking examples. In the marble cladding, the Architect interprets, reworks, and implements the teaching of the past. At the same time, he developed an almost scientific methodology, using his mathematical skills and new theories and technological practices, making the *Casa delle Armi* a work aimed at seeking a new classicism. The external cladding in Carrara veined statuary marble has a design of the slabs developed very carefully by Moretti, who wanted to give the impression that the building was made from a single block of marble, almost a sculpture. The slabs, with thickness from 2 to 5 centimeters, in the linear parts of the elevations, have a variable height starting from 48 cm at the base of the building and then gradually decreasing upwards with bands of 47 and 46 cm. The curvilinear slabs placed in the joints have considerable architectural and technological value. The *Casa delle Armi* fits perfectly into the personal research of Moretti aimed at identifying a modern

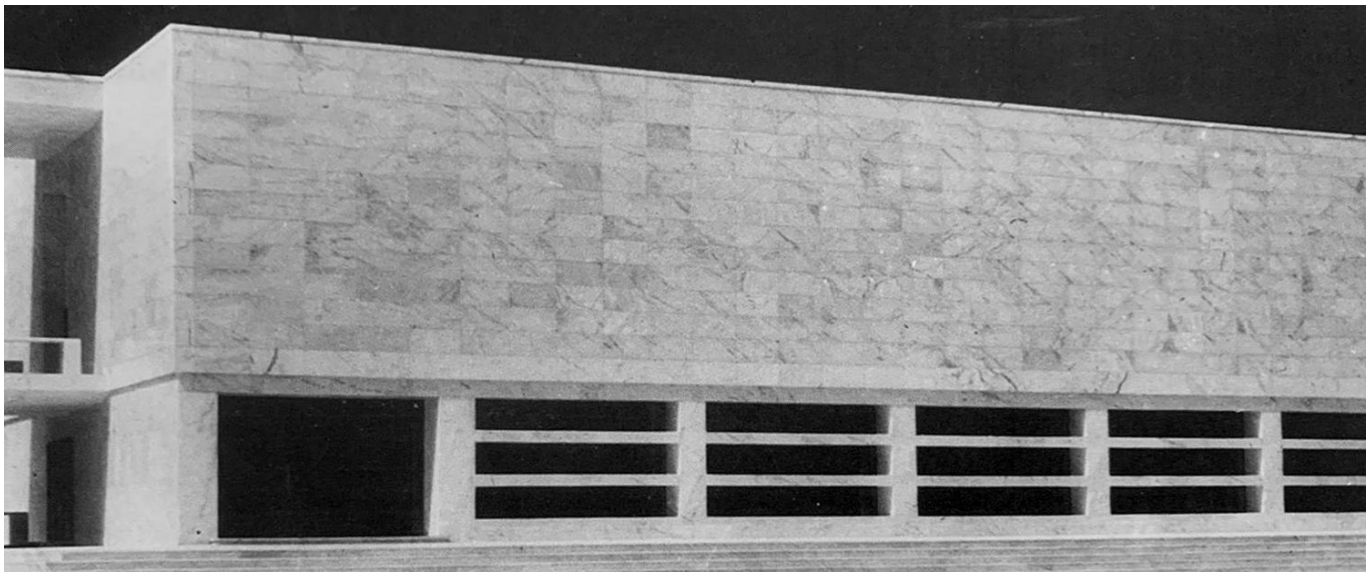

Fig. 1. *Casa delle Armi, Rome, 1935. (Photo © Sport e Salute Spa, Direzione Infrastrutture Sistemi e Ingegneria Dello Sport - Archivio storico CONI).*

architecture capable of alluding to classicism without repeating the forms. Plinio Marconi underlined this aspect in the article mentioned above published in *Architettura* in August 1937: «On the outside, the *Casa delle Armi* is completely covered with Carrara veined marble slabs, which vary in height from cm 48 at the base of the building, to 47 and then 46 at the top. The squares, the tub, and the external floor guides are in common Carrara marble».

3.2. THE FACADE CLADDING AND THE MORETTI ABACUS

In the archival documentation, there are tables of the orders of the marble slabs that surround, like a marble skin, the *Casa delle Armi* and that – in a systemic, mathematical, and technological way – generate a maieutic and prodromic study on the technology of stone material in modern times. These slabs, signed by the Architect on March 10, 1935, were represented in a special abacus, complete and complex, and sent directly to the quarry Simonelli Marina di Carrara.

The choice of the cladding of the artifact is the result of Moretti's studies on baroque and classicism combined with his mathematical-operational research and revision of past architecture, identifying those fundamental and symbolic aspects that, when transferred to contemporary architecture, give it new strength. The intent is to extract from the works of antiquity those geometric, functional, and spatial rules that govern the architecture and its space. Moretti's relationship with the constructions of the past clearly emerges from the cognitive investigation of the rules of the artifact, highlighted by the generative geometric matrices that characterize the design of the elevations and the base of the abacus of the stone blocks. Moretti declares and pays particular attention to the need to act in the design process of his prospects with an approach that finds its starting point in the mathematical formulation. In the design approach to the representation of the exterior marble cladding, the Architect reveals with immediacy the mathematical rule that highlights the univocal link between external and internal with balances of forces represented in the thickness and connections of the slabs that concretize the Vitruvian triad: *venustas-utilitas-firmitas*.

These concepts can be deduced and found in the external cladding abacus tables, divided into lot A and lot B, respectively, for the Hall of weapons and the Library volume. Each slab follows the geometric characteristics in function of the vertical and horizontal placement and the activities housed in the interior of the volume. The different thicknesses of the slabs are identified, from the photographic survey, in correspondence with the internal hosted functions so that the observer can read the architecture from the outside to the inside without revealing the structure covered and protected by the stone material. The slabs, divided in alphabetical order, from A to Z, have specific characteristics: they are wider near the

elevation angle and higher, vertically, while going up. The thickness varies from 2 to 3 cm in the linear parts, reaching a thickness of 10 cm for the special elements placed at the corners. The latter, like the curvilinear strokes, have been obtained from unique marble blocks following the technique of "cutting to the reverse", so each type of slab is considered as a single piece whose calculations and drawings are specified in the tables, slab after slab, without neglecting any geometric details. The best-known facade in the historical photographs has been examined in detail to better understand the compositional criteria of the stone cladding. The facade is that of the gym, photographed by Alinari and Vasari between 1935 and 1936, then promoted in the magazine *Architettura* of 1937 and, since then, always identified with the exterior of the *Casa delle Armi*, as reported in documents: *Casa Sperimentale al Foro Mussolini* – Lot A (gym), Order I (facade towards the *Foresteria*). In the orders of this facade appear 1052 ordered slabs for a total area of approximately 500 square meters.

In the table, there are special pieces such as the S-shaped slabs and the 55 cm x 10 cm linear one, with 1 cm x 1 cm x 2 cm indentation, placed as a finishing layer on the facade cladding with the indentation as a drip edge. Among the corner slabs of particular interest is the T of only two pieces, size 104 cm x 104 cm x 55 cm, with a recess in the corner part, which, drawn in dashed line, acts as a 2 cm deep drip edge. The other corner slabs of the above-cited table are the U and V. The first one has 26 pieces of orders, while the second one has only 2 of them, like the T. The V has relatively small dimensions, 30 cm x 30 cm with a thickness of 5 cm, while the U has wings of different sizes, that is 58 cm x 38 cm with a thickness of 10 cm. Both slabs have a rounded inner corner. The curved solid blocks, specially designed for all atypical concave and convex places in order to make a softer transition between one surface and the other, are particular and of great interest, because they give the building the image of a classic and abstract monolith, made of matter ideally compact and free of connections. The slab that covers most of the surface on the façade is the A, 48 cm x 100 cm for a total of 420 pieces, occupying the central part of the facade. In order to deepen the study of the stone slabs of the facade and understand their characteristics, and also better define the technique used by Moretti, the weight of slab A was calculated considering it as a sample: given slab A of the aforementioned facade, with dimensions 48 cm x 100 cm and thickness 2 cm, and the specific weight of the statuary veined marble of Carrara, 2702 kg/mc, gives the total weight of the slab equal to 25.94 kg. From the calculation, the slab is light and delicate as to defend well the body of the wall, concealing, in particular, the internal structure, with a reference even to Borromini's technique, revisited in a modern key.

The technique of positioning thin slabs is typical of the 30s in Europe. The cut of the material, of mechanical type, allowed to obtain, from a block of marble more slabs of 2–4 cm thick. The laying work provided that the elements had to be fixed to the structure and the infill wall by previously mounted metal anchors. For this reason, the cut took place along the veins, contrary to what happened in previous eras, as it was no longer the compressive resistance to matter but the one to the impact and bending. After the cut, the slabs were expected to be polished off by rubbing, using mechanical ground tools and lead filings, after moistening the slab's surface with potassium alum water. Special holes were provided for fixing the slabs to the structure and infill wall on metal anchors previously mounted. The technique was different from the one used, for example, in the same period in America. In that case, it was used to mount a thicker cladding, between 12 and 20 cm, in which the stone blocks supported each other like an independent wall, which was built together with the structure. The stabilization of the cladding was necessary, above all, for tall buildings – e.g., for the first skyscrapers – through metallic elements that tied the slabs between them and to the structure.

The marble slabs of the *Casa delle Armi* are attached to the wall by a layer of mortar and fixed reinforcing anchors in the wall itself. The fact that it was a usual technique is confirmed by the fact that its description is little present in the archival documents, just sketched in the margin of some tables. The resulting structural problems can be deduced from photographic surveys, where it is seen that the surface below the slab appears perfectly smooth; this is due to the different thermal expansion between marble and mortar. This phenomenon is particularly evident in the elevations facing south because they

are more exposed to the sun. In correspondence with the fixings, the metal anchors are present only in some cases. It should be noted that the cladding technique described above was not applied to architraves and ceilings for aesthetic and functional reasons. Orders for the slabs were signed by Moretti in March 1935 and requested by Marina di Carrara in Rome by the end of the month indicated in the orders. Along with the specifications on the drawings, there are precise indications to follow in the preparation and shipping phase of the stone slabs, manually written by Moretti. He had recommended that «all the slab elements […] had to have a surface perfectly

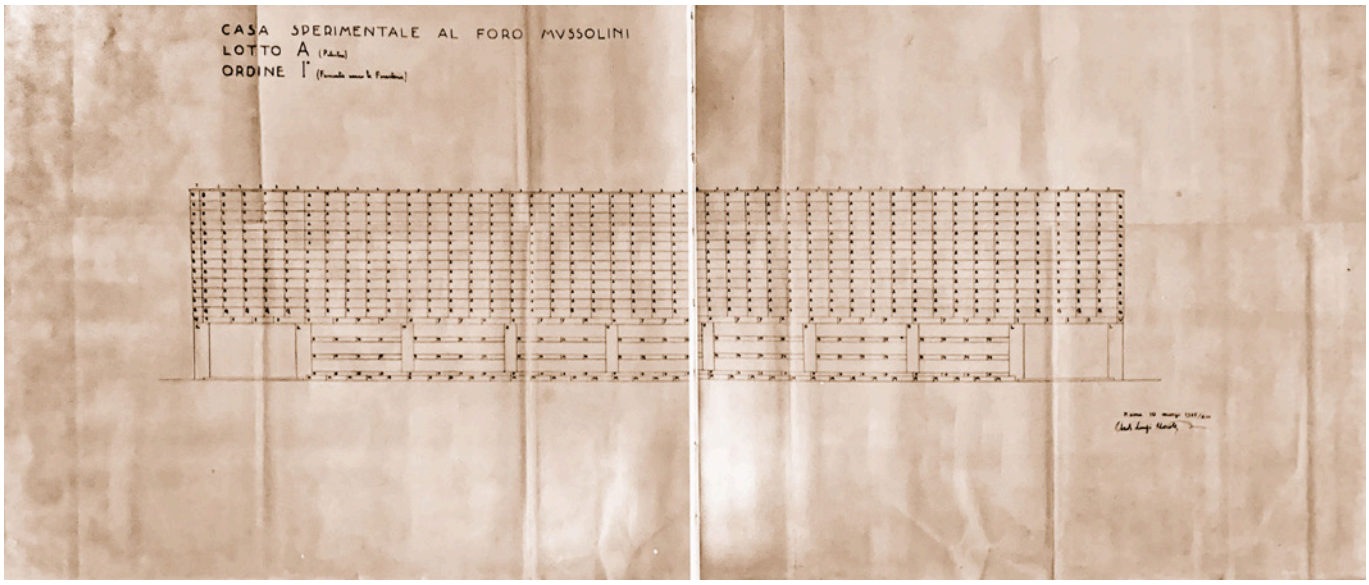

Fig. 2. *Moretti Abacus for one of the facades.*

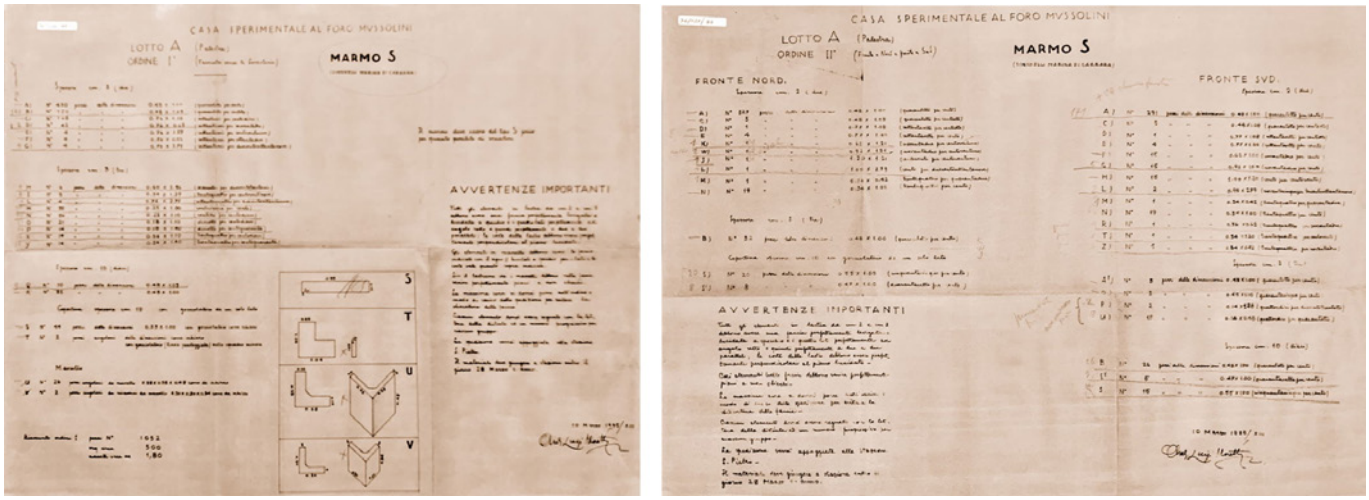

Fig. 3. *Drawings of the commercial orders for the marble slabs.*

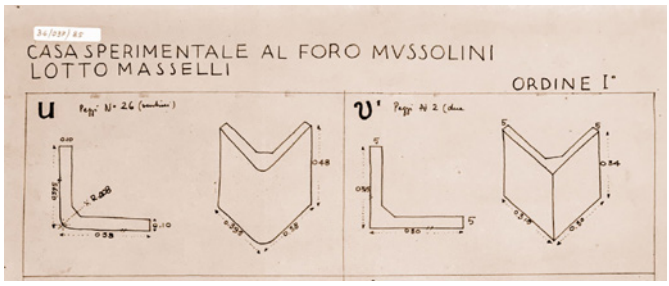

Fig. 4. *Moretti Abacus: detail of the corner slabs U and V.*

polished to mirror and the four sides […] perfectly parallel with each opposite side; the edges of the slabs must be perfectly perpendicular to the polished surface. […] Both the slab and the solid must come perfectly flat in the faces. The utmost care must be taken when loading the shipment to avoid the bending of the faces. Each element must be marked with the letter of the bill and a progressive number for each group».

3.3. COMPARISON BETWEEN THE ABACUS, THE BUILDING IN 1937, AND THE CURRENT STATE

Once chosen the facade to be studied, a macroscopic analysis has been carried out by comparing Moretti's abacus of the selected facade and the photos from 1937 (the year of the inauguration of the building) and those from January 2021. The choice of these three images is because they represent significant moments of the building's history: the design project, the inauguration, and the current state. These phases will be considered in the digitalization of the building, creating a model that can represent and describe its different phases to share knowledge on the building's history and plan maintenance activities.

After straightening and scaling the photos, the images are placed side by side and compared. This study aims to understand if there have been any changes during the construction phase compared to the original project and also to identify any interventions or replacements on the original marble slabs carried out to date, given the scarce presence of archival information on the restoration activities on the stone envelope of the *Casa delle Armi*. Therefore, this macroscopic analysis is preliminary for further, more in-depth investigations that will be able to verify the hypotheses made by the photographic comparison.

Thanks to the comparison of the archival documents and the photographs of today with Moretti's abacus, it can be deduced that the building construction precisely followed the design project, at least as regards the arrangement of the marble slabs. Furthermore, the slabs visible today appear to be the same as those in the inauguration photo – except for the second slab in the seventh row: the darker slabs and the more pronounced veins are clearly visible in both photographs.

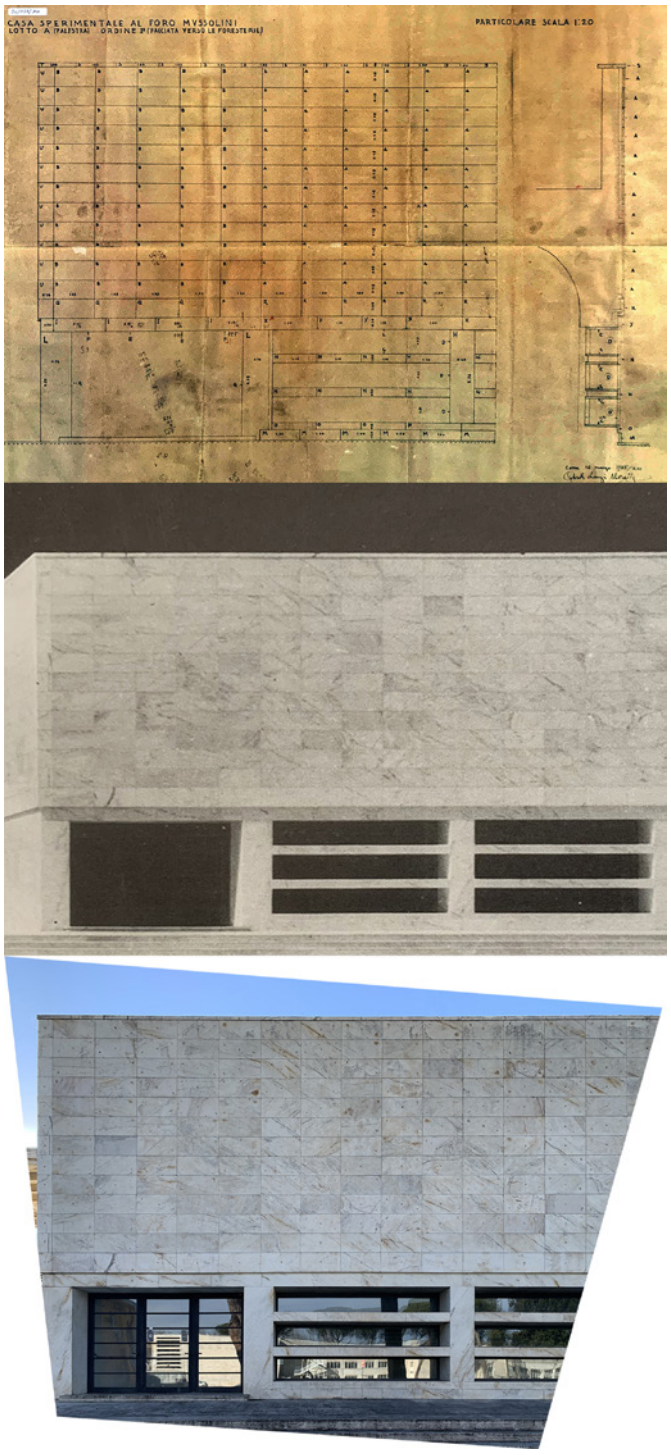

Fig. 5. *Photographic comparison between the abacus, the façade in 1937 and nowadays.*

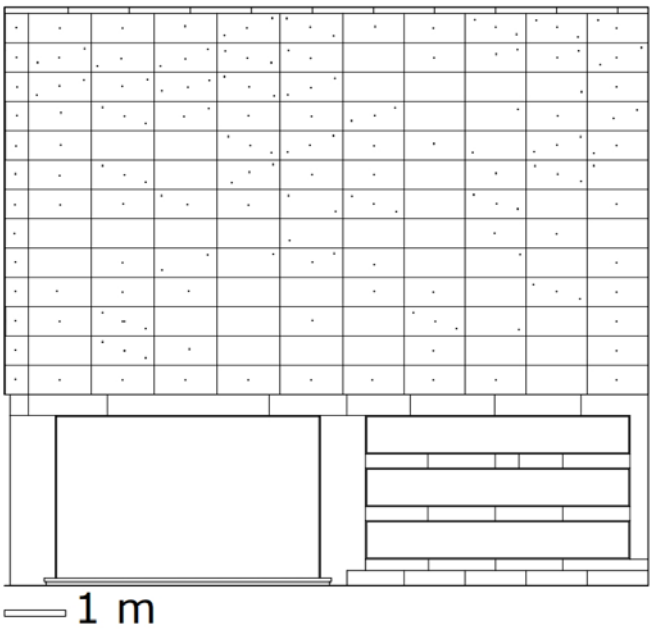

Fig. 6. *Part of the considered facade on which the metallic elements are highlighted.*

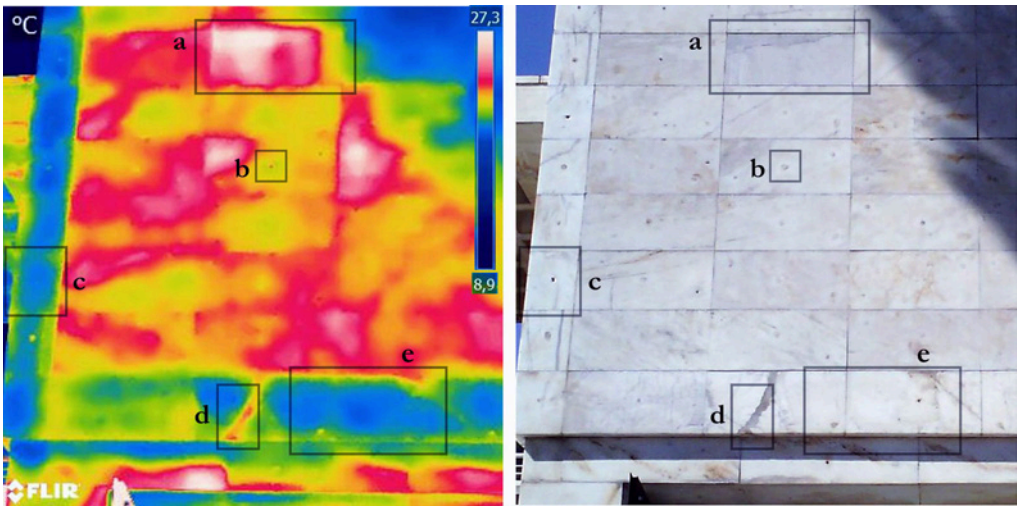

Fig. 7. *Thermographic analysis on a portion of the considered façade.*

The photographic comparison shows some additional metal elements put on the envelope irregularly, intending to further hold the thin slabs. These elements can be visible, from 1 to 3, in most of the slabs but not on all of them.

Another analysis is conducted employing a thermographic camera. This tool allows for non-destructive testing that can give important information on the construction techniques or the material and its level of decay. Figure 7 compares the thermographic image (on the left) and the photograph (on the right) of the same part of the considered façade. Through this comparison, some information can be found (Fig. 7):

- different thermal behavior of a replaced slab (a);
- the presence of metal elements (b);
- the presence of some thicker marble slabs on the corners and the lower row (c);
- the different thermal behavior of the veins that can bring to a faster decay because of the different thermal expansions (d) (e).

Finally, further non-destructive testing has been performed on a portion of the façade to measure the thermal flux crossing the envelope and assess the thermal transmittance. Results (Fig. 5) show that indoor temperature, as expected, is much more stable due to the thermal inertia of the wall than the outdoor temperature. Indoor temperature varies from 16 to 20°C, while outdoor temperature ranges from 2 to 21°C. The thermal transmittance is equal to 0.53 W/m²K.

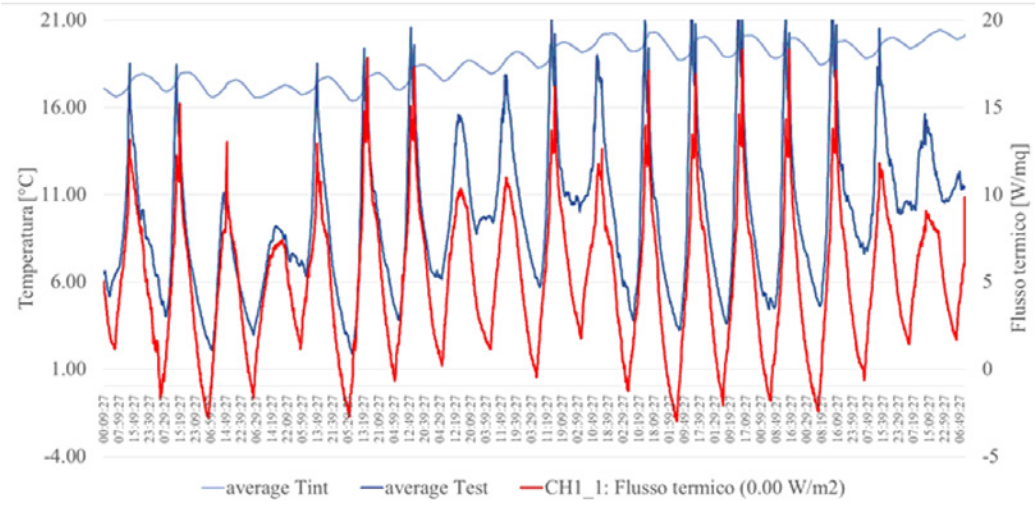

Fig. 8. *Results of thermal flux measurements.*

4. CONCLUSIONS

The results described in the previous paragraph are only an exemplary part of the information available on the *Casa delle Armi*. Currently, the documentary research phase can be considered concluded. The information already available in the scientific literature and the consulted archives have been integrated by the research in the marble mine mentioned above and by further data emerging from the research work carried out by the aforementioned Vannucchi [16].

The geometric survey of the facades has already been done but can be integrated by applying digital techniques not available in the previous phase, such as the laser scanner and the aerial survey drone. The point clouds, in this case, lead to errors due to the possible interference of the marble veins, which the recognition algorithm tends to confuse with the metal elements on the slabs and the joints between the slabs themselves.

Thermography, as mentioned, also integrates the geometric survey in identifying discontinuities that are not visible externally, which are highlighted by the variation in heat capacity that leads to a difference in temperature as a result of daily thermal excursions. Even the combined effects of sun exposure and pollution can be highlighted with this system.

The reconstruction of the maintenance interventions is expected to be more demanding because many of those activities are not testified by documents, but they are clearly evident, as this work has shown, in the effects of deterioration that they have caused.

The digitization phase will need to organize the whole knowledge of the building in a compatible way with the dimensions of a building information model. This phase, which has already begun and tested on individual slabs, will be the subject of specific study as part of the national research program mentioned in the introduction of the paper.

At the end of this discussion, the profound difference between the knowledge of the building and the historical, geometric, in-field monitoring and construction analysis described so far should be emphasized. Indeed, the actual knowledge involves understanding and reconstructing – the so-called "decoding" – the genetic and creating criteria of the work – the marble envelope. For Moretti, these criteria correspond to real "classic" harmonic rules and require a specific design approach to be correctly understood and interpreted. In this sense, the main difficulty of the digitization process lies in modeling it according to this approach, when only numerical values can be used for the model creation. On the other hand, only from this understanding the restoration project will be able to start, aiming to reconstruct not the simple geometry but the actual shape of the studied architecture.

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