Application of a digital framework towards the comprehension and restoration of the thin marble envelope of the “Casa delle Armi” built cultural heritage

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Abstract: Cultural heritage sites and architectural heritage are inestimable assets to preserve and play a vital role in the tourism sector of urban areas as well. Therefore, their preservation, usage and maintenance are crucial, so they can be shared with citizens and visitors. Italy is one of the richest countries with respect to the quantity and prominence of cultural heritage and built cultural heritage, and at the same time a significant part of the built heritage is in need of effective restoration strategies. The growth in information technologies (ITs) for both the construction sector and tourism, as well as citizens’ life, opens up new scenarios for built heritage preservation, maintenance and enjoyment. The objective of this work is illustrating a digital, BIM-based framework applied towards the preservation of the built heritage. In particular, a famous built heritage, the "Casa delle Armi" (Luigi Moretti, 1937), is considered to apply such a framework.

Keywords: digital cultural heritage; built cultural heritage; rationalist heritage; marble envelope; restoration; Luigi Walter Moretti
**Reference** to this paper should be made as follows: Ferreo, M., Rosso, F., Arena, G. and Vannucchi, N. (2020) ‘Application of a digital framework towards the comprehension and restoration of the thin marble envelope of the “Casa delle Armi” built cultural heritage’, *Int. J. Digital Culture and Electronic Tourism*, XXX

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1 Introduction

Cultural heritage is one of the main drivers for tourism, and this is particularly true in Italy, where there is a high concentration of heritage sites and heritage buildings. Indeed, the 1.8% of the Italian historical buildings (which are 12.5 million, as of 2015) are cultural heritage buildings [1]. In particular, heritage buildings and tourism have a strict relation, as heritage buildings render the city “an experiential space filled with emotion, mindfulness, engagement and personal meaning” [2], thus being fundamental for the promotion of a specific townscape [3,4].

At the same time, cultural heritage sites in Italy are often in need of renovation towards maintenance [1,5,6], as well as of a higher involvement of citizens [7] in order to be economically self-sustainable while providing for their conservation and preservation, which entails their social sustainability role [8]. Indeed, cultural heritage contributes to literacy and reaching a wider audience enlarges the number of citizens benefiting from increased literacy. Moreover, as evidenced in previous works, the growing attention on environmental sustainability for the built heritage calls for a conservation and maintenance that is conscious of such energy-efficiency and consumptions’ reduction challenges [1,9,10]. With respect to this call for environmental sustainability, Franco and colleagues [11,12] demonstrated that sustainability-aimed actions in the tourism industry financially benefit companies that carry on such actions, as stakeholders are sensitive to them. In this panorama, the conservation and renovation of the building heritage should be planned based on the three pillars of sustainability, namely social, economic and environmental sustainability [13], which are intertwined. One mean by which building heritage can pursue such objectives is digitalization, intended as “the process of generating, collecting, and analysing data to create value” [14], as it was demonstrated to be effective in other contexts like museums, tourism and healthcare [15–18].

Based on these considerations, we propose a digital framework for the restoration of the building heritage, with the above-described objective to improve the social, economic and environmental sustainability linked to the building heritage. In so doing, we select a peculiar case study, which is exemplificative of an important and delicate part of the Italian building heritage, and illustrate the framework on this example. Nonetheless, the proposed digital framework is of general value, and theoretically applicable to a wide part of the building heritage, characterized by this peculiar marble envelope.

The illustrative case is “Casa delle Armi” building, by architect Luigi Moretti (Fig. 1). It is located in the roman “Foro Italico”, the historic sport complex built in the ‘30s. The building is one of the masterpieces of modern marble architecture characterizing the first half of 1900 [19–21]. Indeed, it was the first building to be covered with a marble envelope in Rome in the modern era, and its construction had a tremendous impact on the architecture of the period before the II World War (1939), the Italian rationalism, leading to its inclusion in the cultural heritage category. Therefore, the envelope is critical and crucial for the cultural heritage we are considering. The most immediate challenge for the building, as for many other cultural heritage employing the same construction techniques, is related to the maintenance and preservation of the envelope, which is therefore the focus of this research work.
The exemplar envelope is nowadays degraded and in need of urgent restoration towards a sustainable and conscious conservation. Some of the slabs composing such an envelope are heavily damaged and at collapse risk, posing a serious threat to the utilization of some parts of the building and preventing visit-related activities. The article spurs from a research collaboration with CONI, who actually is in charge of the Foro Italico, aimed at preserving the marble envelope of the building.

As the largest part of the building heritage, the considered exemplificative building has a complex story and was subject of numerous successive interventions, which were carried out in past decades on the marble slabs composing the envelope. Such interventions were most often cause of additional degradation and are not always documented in an exhaustive way.

As stated above, the present manuscript proposes a digital framework for the restoration of the building heritage, in consideration of social, economic and environmental sustainability. The theoretical framework is here exemplified towards the envelope restoration challenge, by exploiting the digital possibilities related to Building Information Modelling (BIM). BIM allows information production, management and delivery among the stakeholders involved in the architectural project. When applied to historic buildings, BIM is usually referred to as HBIM, i.e., Heritage BIM [22]. As reported in Hull and Ewart work [23], HBIM has a strong focus on digital documentation by means of 3d data capture, but still few applications in operations and maintenance actions. The integration of different dimensions of building construction and management has led to the definition of multi-dimensional BIM processes [24], starting from the 3d geometric representation. BIM allows to add dimensions to the information, such as 4d BIM, which includes also planning and simulations activities, 5D BIM that considers costs, 6D BIM that includes sustainability-related information for life cycle assessment evaluation, 7D for operations and management activities, and so on: the more the dimensions, the richer the digital model. For HBIM, some challenges have been identified, which are linked to uncertain data of historic constructions. Therefore, the here proposed BIM-based theoretical framework is specifically designed to solve the uncertainties related to data on the marble envelope and to frame the information so that they can be employed for preservation and restorations actions, as well as to guide the maintenance of the envelope. To do so, a complete knowledge and comprehension of the complex history of each slab composing the envelope is needed, given the peculiarity of the material and of the technological application as envelope component.

In greater detail, the framework, proposes an “informative abacus” based on BIM, and would allow to frame and classify the data related to each element composing the envelope, both graphically and numerically, towards restoration. The framework would allow for comprehensive analyses aimed at restoration, maintenance and fruition activities: simultaneous costs/benefits, technical/construction and design evaluations could be conducted to guide the strategy of intervention on such scientific basis, founded on the overall and complex consideration of the elements concurring to the strategy determination. While similar BIM-based methods have been described in previous research for specific case studies [23,24] the original contribution of this work, is to posit the conceptual bases of the framework, to provide a first theoretical contribution to apply the BIM-based digital approach to the building heritage pertaining to rationalist architecture, with thin marble envelope, which are typical of the 1920s’-1940s’ in Italy, and that, due to the technological characteristics of the construction, are in particular need of a conscious restoration and conservation. This research is of particular relevance, as its application
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would allow to avoid deleterious interventions, which have instead characterized such cultural heritage in the past decades, leading to increased degradation; and to solve once for all the uncertainties related to the peculiar construction elements.

The article is structured as follows: the methodology, which further articulates subsections about the relevant case study building and its envelope, is presented in the second section of the work; then, the results section illustrates the conceptual digital framework; and the discussion section debates the challenges related to the setting of the framework and its application; finally, the conclusions synthesize the main findings of the work, its limitations and its relevance.

Fig. 1. Historical photo of the case study building; the marble envelope is clearly visible

2 Methodology

This research aims at setting the bases for designing and developing the digital framework, which we can define as an “informative abacus” for the restoration and maintenance of built cultural heritage with thin marble envelope, which is the focus of the preservation and maintenance actions, due to the urgency of such actions. We define such framework “digital” as it is based on the new possibilities, above-discussed, offered by digitalization, and in particular by BIM. The framework is based on the main pillars that we recalled in the introduction, namely the urgent need for preservation and restoration; the need to properly exploit and share the cultural heritage sites for citizens and visitors; the new opportunities spawning from digitalization; while at the same time aiming at social, economic and environmental sustainability. The methodology of the paper is thus constituted by the careful analysis and knowledge acquisition on the case study building history, with a specific focus on the history and past intervention that were performed on the envelope. Indeed, these information are fundamental to define the uncertainties linked to the construction features of the envelope, and in consideration of the need of solving such uncertainties towards a more effective and reliable digitalization of the data related to the building. Therefore, in the first part of the article, the history of the exemplificative
case study and its envelope are described, highlighting the focal information to be gathered in the digital framework. Then, the results section takes its moves from such a complex history to propose the digital framework, which is widely discussed in the discussion sections.

2.1 The case study building: a significant built heritage

The Casa delle Armi (Fig.1), a masterpiece of the architect Luigi Walter Moretti, better known as the Accademia della Scherma and, in the first denomination, as the Casa Sperimentale Balilla, is located within the sports complex of the Mussolini Forum, now Foro Italico. It is located at the top of the southern entrance, and it was born as an advanced typological experiment. It is indeed considered the most innovative of the “Balilla National Opera” buildings. Moretti creates an architecture with a clear image and with significant functional complexity.

The strategic location of the building, at the end of Viale Angelico and connected to the historic city and San Pietro (Vatican City), allowed for a representative designation. The historical photos taken by Vasari document the construction period between the end of ’34 and April 15, 1936, the date on which Mussolini’s official visit to the investigated building, the Fencing Academy, was pictured. The black and white photos by Vasari were selected by Moretti himself and allowed for an accurate and detailed documentation of the original work, at the same time contributing to the identification of the building as an icon of modern architecture.

1937 is the year of completion of the work witnessed by the publication of an article, with an accurate description by Plinio Marconi, on "Architecture" - official magazine of the national union of fascist architects -. There are various documentary evidences according to which Moretti was present daily on site to take care of the details of his creation, with corrections made also during the work in progress. This is evident from the analysis of the project technical drawings, enriched by sketches and notes that changed during the construction phase and, in particular, by his accurate abacus of the orders of the marble envelope, in which the architect reported and numbered individually each slab, with scrupulous detail. On 9 May 1936, the inauguration of the first exhibition at the Accademia di Scherma is celebrated, with the "Exhibition of the domestic economy".

In 1937, on the occasion of the "Sports Building for Youth Exhibition", the photos brought to light the details, internal and external, of the marble cladding, showing the peculiar characteristics and enhancing the shapes and dimensions of the slabs of the facade. Because of the war events, there is no further documentary evidence on the building until May 6, 1944, the date when the Italian Youth Commissariat was established, to take over the property of the former Foro Mussolini. As of June 4, 1944, the sports complex, following the entry of American allies into Rome, houses the "V Army" of General Mark W. Clark. The building is employed as a center for the rehabilitation and recovery of injured American soldiers.

Successively, 1951 represents a crucial year for Italian sport, because the Foro Italico, thanks to the political strategies of CONI President Giulio Onesti, becomes the headquarter of the National Olympic Committee and Rome is selected as the city for the 17th edition of the 1960 Olympic Games. The analyzed building, alongside with many others of the complex, were granted for the Olympic Games, by means of a historic agreement between the General Commissioner for Italian Youth and CONI. Despite the good state of
conservation of the work, the Casa delle Armi was not used as a venue for fencing competitions during the 1960 Olympics.

In the historical photos of 1971 by Francesco D’Asaro, published in the magazine of the Provincial Order of Architects of Rome and Rieti, the Casa delle Armi appears as a degraded building both inside and out. The photos highlight the deterioration of the marble skin of the cladding, the facades, and the external stairways appear to be disfigured. Black crusts and an advanced anthropic degradation are clearly visible, irrefutable signs of the lack of care and maintenance of the building.

In 1977 the fencing complex was transformed into a courtroom: a "bunkerization" program transformed it into a maximum-security building and it was used for the trial of the terrorists, responsible for the kidnapping of Aldo Moro. The 2000s marked the various passages relating to the decrees of the Minister of the Treasury to the Ministry of Economy and Finance that with Ministerial Decree 71856/2005 granted the use of the asset to CONI Servizi, to whom it was definitively returned by the Carabinieri in 2011. Since 2013, following the need and desire to make the Casa delle Armi again actively part of the Foro Italico, a restoration work began, aimed at recovering the building through ongoing studies with the objective of restoring the work in compliance with its original beauty, to preserve the cultural heritage, and to render it usable and visible for the general public (citizens, sport activities/visitors activities).

2.2 The focus: the marble envelope

The current state of the marble envelope is due to different concurring factors, namely the construction technology that was employed to apply the thin stone slabs, the successive interventions on the envelope, the nature of the material and the aggressive outdoor environment.

With respect to the first two factors, the stone elements are glued to the wall by means of a layer of mortar; reinforcement anchor bolt, embedded in the same wall, further connect the slabs to the wall. This solution derives from wall cladding techniques and was considered to be completely ordinary at the time. Indeed, in Moretti’s drawings relating to the cladding, there are almost exclusively studies and orders on the shape and size of the stone elements, without details on how to fix them in place.

However such a technique to apply the thin slabs is one of the causes of degradation as evidenced by analyzing the façade (Fig. 2), due to the different thermal expansion coefficients of marble and mortar, as well as to fragility imposed to the thin marble elements by inserting the anchor bolts in the already reduced thickness of the slab, which is equal to 2 cm most often, up to 3 cm for thicker special elements.

Moreover, the characteristics of the natural stone material, together with the low thickness, cause differential thermal expansion between the two faces of the slab, that one facing the inside and that one the outside of the envelope, provoking the element bowing. Such issues on the marble façades, on their turn, implied the need to intervene on the envelope to regain stability of the slabs. The chosen solution was the use of additional anchoring bolts, puncturing the slab and clearly visible on the envelope. Such a solution proven unsuccessful and further aggravated the state of the facades, causing not only stability but also discoloring and staining issues. Successive interventions consisted also in the cleaning of the marble façades, which washed away parts of the stone material and rendered it even more subject to the aggressions of the external environment. Later on,
other interventions were conducted specifically on some parts of the facades, solving discoloration, staining and black crusts, while leaving the same issues on the remaining facades.

Therefore, the envelope on the different facades, and each single slab, have had a different story and have different characteristics, with respect to the aesthetic and stability aspects. This matter of fact highlights the need for a synthetic and updated abacus reporting not only the geometry and intrinsic characteristics of the marble slabs, but also the successive interventions. The advancements in digital technologies allow to design and compile a digital abacus gathering all these data, which can be updated and considered for the future maintenance and sharing of this unique and exemplificative envelope. Such a solution, which is more clearly described in the next sections, is aimed not only at maintenance activities, to restitute the envelope –and the building- to be safely employed, but especially to set a strategy and a digital, implementable basis to safeguard such heritage for the next generations, and to share its history, technical excellence and features with citizens, visitors and professionals alike.

Fig. 2. Actual deterioration of the stone envelope

Considering that (i) the building is part of the cultural heritage buildings of the Italian modern architecture and it is characterized by the peculiar thin marble elements on the facades; (ii) it is in urgent need of preservation and conservation actions to be shared and used again; (iii) the complex history of the building and its marble envelope, which complicate the digitalization and gathering of certain data, it represents a relevant case study [25,26] on which to base the proposed framework. Thanks to this, the outcomes of this research can be generalized to serve other buildings with similar history and characteristics.

3 Results: the conceptual digital framework for the informative abacus
Digitalization of all the above discussed information would allow to generate a homogenous knowledge base, collected in a convenient way, which would allow easy consultation and value creation towards preservation, restoration and maintenance actions, to start with. The “informative abacus” is the digital version of the classic “abacus”, which is a technical drawing depicting the geometry and other information about each single marble slab. Below, all the gathered information on the slabs, which are functional to avoid uncertainties and errors in the informative abacus, are discussed.

The processing of stone construction elements is necessarily carried out in the factory; this implies the need to plan in advance and in high detail every single construction element. In many cases, this work is directly carried out by the marble supplier. Luigi Moretti, however, attributed great importance to the stone envelope in the architectural perspective of the building. Therefore, he designed and sized every single element, from the flat slabs of the facade to the rounded blocks that define the corners, as well as every other part of the cladding.

In doing so, moreover, the architect was able to differentiate the dimensions so as to align the joints between the slabs in a grid that perfectly marks the shapes of the facades. The meticulous study also includes some architectural “tricks” to accentuate the perspective effect of these alignments. Such expedient is a reinterpretation of the optical corrections already known in architectural history and applied, for example, in the Parthenon in Athens. As of today, Moretti’s designs are still available, in the form of graphic abacus (technical drawings) that were used at the time to transmit marble orders to suppliers. These abacus are famous design works, published in magazines and books [27,28].

Starting from these abacus, the first phase in the knowledge of the building, is a mandatory comparison with the actual envelope, in order to verify whether the envelope project corresponds to the actual construction or not. This step requires a survey of the facade by measuring each individual slab and comparing the result with the architect's design. This operation already started on some sample slabs and showed a good agreement between design and construction. To systematically carry out the entire survey, it is planned to use a laser scanner system, integrating point-cloud surveys with a simplified three-dimensional model of the facade. This is possible because, being a rationalist-style work, the geometry of the whole and of the various elements is satisfactorily attributable to elementary geometric shapes.

It should be noted that a three-dimensional survey such that commonly used in restoration works is not necessary. In this case, in fact, it is sufficient to establish the size and position of each slab or block. The main reasons are two: 1. The study concerns the conditions of each slab and no changes are foreseen - nor are they conceivable - in the composition grid of the coating. 2. Luigi Moretti’s architecture is a rationalist-style and geometric architecture, therefore restoration must return the morphological perfection to which the architect aspired, regardless of executive imperfections. From what has been established so far, it follows that the outcome of the first knowledge phase is the development of an updated abacus of the stone facade, created by returning the survey through a two-dimensional model of each façade of the building. For these graphic elaborations, an object-oriented BIM type software is used, which recognizes each element of the envelope as a slab or block of marble.

The advantages of such a tool compared to the traditional application of a simple computer-aided design (CAD) with geometric primitives are many and important for research purposes. Indeed, CAD model return the merely geometric configuration of the represented object. Instead, the element modelled by means of BIM-based tool is a
multidimensional object to which, in addition to the shape and coordinates - in this case
two-dimensional - a series of other data is associated, both geometric (thickness and shape),
and related to the material and its intrinsic characteristics, as well as related to the state of
degradation. These are what we recalled in the introduction section as the “multi-
dimensions” allowed by BIM models.

A similar method was presented in a recent study by A. Cernaro [29], who applied it in
a case that has similarities with the one considered here: the stone envelope of the Central
and Maritime Station of Messina, designed and built more or less in the same years of the
Casa delle Armi, by Angiolo Mazzoni, a leading figure in the architecture of the Regime.
In addition to having in common the time of construction and the material used, the two
works both had a complex history of subsequent interventions. While considering the work
of Cernaro, in this research we aim at systematizing the method as a digital framework,
which could then be applied to all the building heritage with similar envelopes.

The reconstruction of the "construction history" is one of the greatest difficulties both
at the study level and at the level of data insertion in the BIM model. With regard to the
first problem, as we have seen, after Moretti’s abacus there is no certain information on the
maintenance operations, which however are evident above all for the currently
recognizable negative effects: there are anchors that have become visible, replacement of
slabs with others of different marble, cleaning performed with aggressive products. With
regard to the second problem, the software used by Cernaro (Autodesk Revit®) allows to
assign only one phase of realization to each element, without being able to record any
intermediate interventions. In this case, for the purposes of the restoration intervention,
only the current state of fact matters and therefore the difficulties listed above are not a
problem.

In summary, the creation of a "digital informative abacus" for Luigi Moretti's Casa delle
Armi is carried out by surveying and returning each section of the elevation in a BIM
model, assigning to each cladding element the necessary additional information.

With respect to the construction of BIM, in general the problems to be addressed fall
into three categories:

1. The definition of data “families”;
2. The definition of the “phases”;
3. The definition of information data.

As far as families are concerned, the envelope is composed by slabs 2 cm, 3 cm and 10
cm thick. The cylindrical body that connects the two wings of the building is covered with
curved slabs. Finally, all the singular points (edges, recesses, connections with windows,
ground connection and roofing) are solved with "blocks", that are three-dimensional
elements suitably designed for each application. The definition of flat slabs is quite simple
and fits seamlessly into a two-dimensional model. The definition of curved slabs can be
assimilated to that of flat slabs by developing the relative elevations in plan. More complex
is the case of the "masselli" (blocks). For the reasons explained above, it is not appropriate
to proceed with a 3D modeling, therefore the blocks are defined as a family in themselves,
described by the projection on the plane of the prospect itself and included in the abacus
with the same information as the flat slabs. Obviously, each block must appear in a single
elevation, even if visible in projection on others; this to avoid being considered twice in
the calculations. It should be noted that the three-dimensional modeling of the blocks,
where deemed necessary for any replacements, must be performed in a separate file; in this
regard, it is believed (this point must be verified) that for this purpose it is advisable to use
parametric modeling software, to facilitate Computer Aided Design (CAD)/ Computer
aided Manufacturing (CAM) integration with the machines that are employed for marble
elements processing, that will manufacture the parts to be replaced.
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With respect to the description of the conditions of the slabs, also in this case - as in Messina - it is useful to apply the definition of "construction phases" of the Revit® software. The reference, however, is not convenient to be strictly temporal (on the other hand, there would not be enough information to do it) but rather related to the construction feature. Therefore, we can preliminarily hypothesize, for indicative purposes, for the exemplificative buildings: elements with original fixing technique (anchor bolts and mortar); elements with passing and visible anchor bolts (50's interventions); elements replaced with non-passing fixing technique; elements replaced with passing fixing technique; detached elements; items removed or dropped. Additions or changes to the definition of the phases will be made following detailed survey. These categories can be easily employed also for other buildings pertaining to the architectural heritage of the same historical period, which, as reported above, are mainly characterized by the same construction technology of the considered case study.

Regarding the definition of the information data to be associated with each element of the cladding, first of all the dimensional data must be considered. To these data, the type of marble is added, essential information for restoration purposes and a difficult information to find [30], as there are many different types of similar marbles, which are not easy to distinguish and entails different behaviors, as well as slightly different aspect. The type and extent of degradation of the material must be considered and associated with the photographic survey of the element. The recording of the thermal characteristics is also expected through the addition of the thermographic survey, which have highlighted a correlation between the data detected by the thermal imager and the state of degradation [31]. Finally, a parametric index of evaluation of possible interventions will be developed, in order to allow an immediate evaluation of the different intervention strategies. Provisionally, the hypothesized sequence is as follows: 1. maintenance; 2. cleaning; 3. surface treatment; 4. consolidation; 5. replacement. Each level is intended as a minimum intervention. Regarding the consolidation, however, different interventions are also being assessed, based on chemical-based interventions, not included in the modeling for now. A conceptual diagram of the focal points of the proposed digital framework is illustrated in Fig. 3.

![Fig. 3. The conceptual model of the digital framework.](image-url)
4 Discussion

The digital framework thus entails a digital model of the building’s envelope to be developed by means of BIM-based tools, which should include the above mentioned data option for each element. Such a model must serve as a reference for the choice of the most adequate and sustainable intervention strategy, and could be also utilized for giving visitors digital information about the built heritage and its peculiar envelope, towards technology-enhanced visiting experiences [32]. The framework increases the sustainability of the building, as a building heritage, in many different ways, in accordance with the three pillars of sustainability. Indeed, it would allow to more consciously choose the most convenient restoration solution, (i) to save and maintain as much as possible the construction material, in order not to waste it (environmental and economic sustainability) and (ii) to maintain updated digital information about the history, characteristics and interventions on the stone envelope and on the building, for both building’s managers and visitors, in order to gather and organize data to create new value propositions (economic and social sustainability) [33].

The data and knowledge that is gathered can thus be transformed into a competitive asset for the built heritage, which, by means of dynamic web-based platforms and hypothetically mobile applications, could benefit not only the heritage management but also visitors [33]. This would favor the passage of the built heritage towards becoming a “smart destination”, which is crucial nowadays for visitors’ experience.

Moreover, the digital framework would also allow a valid decision support system for intervening and managing the built heritage. Indeed, the major technical problems relating to the restoration do not allow, as a whole, a convincing solution and therefore they evidence the need for complex multi-criteria decision support [34]. Multi-criteria decision support would allow to simultaneously evaluate the optimal options for the preservation and restoration, based on different criteria, e.g., the option that is the most economically convenient, the option that saves energy, the option that is technically easier, the option that allow to reduce the restoration time the most. In addition to optimal solutions for each single criteria, there is a multi-criteria optimum solution, which allows to choose the option that maximizes the benefits for all the criteria at the same time. In the sub-sections below, the challenges that should be considered in selecting the optimal strategy are discussed in greater detail.

4.1 Challenges related to the support system and thickness of the marble slabs

Luigi Moretti used to modify his projects several times, as evidenced in many documents (see, for example [35]). However, for the Casa delle Armi, the needs related to placing the orders of the stone elements have imposed an inescapable constraint, at least on the stone envelope. The desire to design every single construction detail made it impossible to make any changes once the marble abacus was completed and forwarded to the marble company that had to produce the construction elements.

This circumstance excludes, therefore, any hypothesis of modification of the building and transforms the preservation of the envelope into a rigorous technical question to obtain a philological restoration that leads back to the original form.

The analyses carried out in this work have shown that one of the main causes of degradation must be attributed to the small thickness of the slabs. The degradation suffered by the limestone by atmospheric agents and pollution has thinned the material in
correspondence with the fixing brackets, constituting the main prerequisite for detachment. The cleaning operations could only lead to a removal of material, with further thinning.

In addition, too thin marble is subject to bending phenomena, a curvature due to viscous sliding of the material. The phenomenon has been known since very remote times [36] and is witnessed in many architecture works, the most famous of which is the Finland Hall in Helsinki, by Alvar Aalto. Many slabs of the envelope exhibit deformations of this type.

There are therefore two conditions which, together, constitute a technical problem that is difficult to solve in the specific case of the considered building, but in similar buildings’ alike: on the one hand, the envelope surface cannot be changed in its configuration, in order not to change the apparent shape or proportions of the building. On the other hand, the thickness of the current slabs is insufficient for the durability of the material. Assuming to slightly reduce the layer of mortar behind the slabs, we can hypothesize to increase the thickness by no more than 1 cm, an amount which is however inadequate to reproduce the original support system with metal anchor bolts inserted in the edge of the slabs. This would lead to the hypothesis of a type of chemical support (substantially, an adhesive), which, however, should be based on a load-bearing capacity of the substrate that is anything but guaranteed.

4.2 Challenges related to marble types and chromatic qualities

Marble, like all natural materials, has a great variety of chromatic nuances even inside the same quarry and, even more so, among the different caves. In this case, the quarry of origin of the original material has been widely exploited and mined over time, to the point where the current quarry front is located tens of meters down than that of the period of construction of the building.

During the construction works, the same architect had discarded a lot of slabs due to the excessive aesthetic differences between the slabs and, in some cases, modified the trend of the marble veins of some slabs by means of painting.

A partial replacement is therefore destined to be visible, as it happens for the portions of the envelope replaced in previous restorations, clearly identifiable because of the strong chromatic differences compared to the originals. On the other hand, a total removal of the coating is certainly impossible both because of the unsustainable cost and because the testimony of the original material would be completely lost. The degradation conditions of the material also exclude removal with subsequent consolidation (for example by resin coating) and restoration of the original slabs; in fact, in all probability, during the removal irreversible breakages of the slabs themselves would occur which would invalidate their recovery.

Whatever the final solution, the currently missing or broken slabs should in any case be replaced, as well as the non-original ones which, as mentioned above, show excessive aesthetic differences and could not be integrated. Therefore, it is necessary to decide whether to accept that the differences between the original and replaced slabs are visible - keeping the historical evidence of the intervention carried out - or try to minimize the differences - while maintaining the identity of the building.

4.3 Challenges related to cost

The high cost of Bianco di Carrara marble is another factor that affects the design choices. From a check carried out in the production basin, the conditions for a promotional or reduced cost supply were not found in consideration of the importance of the building.
Therefore, in the cost/benefit evaluation, the expense for the material has a non-negligible part.

Cleaning tests carried out in the past on undamaged slabs have shown the possibility of obtaining an aesthetically acceptable result without proceeding with more invasive interventions. This type of intervention is less durable and, after a few years, it would bring degradation to occur again. On the other hand, the effect of degrading agents would act in any case and, perhaps with longer times, problems would arise again. Thus, conscious maintenance and prevention actions should be accounted for.

A possible prevention of degradation could be reached by applying on the slabs - both new and original ones - a protective resin treatment capable of adequately filling the micro porosity of the marble. This treatment also has a significant cost and, especially if carried out on site, it does not fully guarantee its durability. In fact, it is necessary to verify both the possibility of progressive leaching by polluting agents and possible alterations of the resin itself, for example yellowing under the action of sunlight.

4.4 Application of the digital framework

The digital model obtained from the "informative abacus", from the digital framework, is particularly suitable to support the decision on the intervention strategy due to its double value, graphic survey on the one hand, data management on the other. In fact, once the cladding has been modeled as described, two different and complementary analysis systems will be available.

A first system is based on the numerical possibilities offered by the software. By obtaining the quantities of slabs in the various situations (in good condition/ to be consolidated/ to be replaced/ missing) and the related dimensional data (surface, weight), it is possible to calculate costs related to different strategies: from the minimum intervention to the complete replacement of the coating.

A second system is based on identifying the location of the slabs on each facade. In fact, the model makes the mapping of the various types of degradation evident, making it possible to evaluate, for example, interventions limited to homogeneous coating areas which, due to their position and/ or exposure conditions, allow not to highlight the differences with other parts treated differently. This duplicity must be considered a strength of the proposed framework, which allows to balance objective and numerical criteria still with a design discretion, which constitutes an essential value in the architectural sector, all the more if - as in this case - we work on a built heritage of historic and artistic value.

In this context, digitalization is decisive. As we have seen, the optimization problem is too complex to deal with and solve with traditional means only, and digitalization would allow creating added value to gathered data.

5 Conclusions

In this work, the conceptual framework for the digitalization of data related to architectural heritage, comprising a digital model and an informative abacus, is proposed towards the restoration and maintenance of said built cultural heritage. The validation of the proposed framework would take place through its application to the case study of the Casa delle Armi, and is a future development of the present work, which deals with setting the theoretical bases of the digital framework. In this regard, the realization of the survey and its return in the BIM software entail an increase in time and costs compared to a traditional
decision-making process based on the assignment of the building for restoration interventions to a company after evaluating the cost estimate.

However, the importance of the architectural heritage and the delicacy of the intervention must be taken into account primarily, with the consideration of implications in terms of safeguarding the cultural heritage, which is crucial towards its sustainable maintenance.

As a secondary result, but not less important, the BIM model can be updated with the modified situation at the end of the restoration and along the years. In that case it will be considered whether to implement further information slots on the existing model or to build a duplicate with the final situation. In any case, this model will have a documentary importance to archive and preserve the construction history (protected from the typical deteriorations of traditional analog and paper documents), as well as to evaluate the effectiveness of the interventions performed and the planning of those eventually needed.

The here presented work is therefore aimed to have a double significance: the technical one, closely linked to the restoration operations carried out, and the methodological one, which is resolved in the development of the proposed framework. The article defines the challenges and information that should be taken into account to frame the digitalization of the architectural heritage. Its original contribution resides in setting the theoretical bases of such a digital framework, especially for building heritage of the 1920s'-1940s’, characterized by thin marble envelope, and advancing the previous BIM-based approaches that were specifically tailored on a single case-study. In so doing, the article still present a relevant case study that is exemplificative and can be employed as a benchmark for the architectural heritage of the same historical period, due to the complexity of the history and of the technical features of the building itself.

It should also be added, in conclusion, that the proposed framework is rightly placed among the studies relating to the HBIM, confirming the potential of digital instruments in helping to enhance and safeguard the artistic and architectural heritage, towards their sharing and their employment; a heritage of humanity that, thanks to digitalization, can receive new attention precisely in the era that seems to undermine its conservation. Moreover, the digital framework would also allow to transform the gathered data into a competitive asset for sharing the built heritage with citizens and visitors, leading it towards smart destination, which on its turn would favor the social and economic sustainability of the heritage. Therefore, the relevance of this study is (i) for researchers in the field of building heritage and architectural heritage and (ii) for practitioners and professionals in the field of architectural engineering and building heritage, as it proposes the bases of a digital framework towards architectural heritage conservation and restoration; (iii) for cultural heritage sites, as they would benefit from the digitalization of their assets, both for operations and maintenance purposes and for educational purposes; (iv) for citizens and visitors, as they would benefit for the increased literacy linked to architectural heritage fruition; (v) for Cultural Heritage Management, as digitalization would allow to more easily store fundamental data on the assets.

Finally, while in this work we focused on setting a digital framework for the architectural heritage of the 1920s’ and the 1940s’ with thin marble envelope, the logical reasoning behind the conceptual bases of the framework are of general relevance, and could be adapted to fit other architectural heritage with different construction technologies and of different historical periods.
Acknowledgements

The Authors are grateful to Sport e Salute Spa and Valerio Petrinca (Sport e Salute Spa) for the availability and support in retrieving documentation and for in field visits; M.F., N.V., F.R. are grateful to Sapienza University for supporting this research with “Progetto di Ricerca di Ateneo”; F.R. gratefully acknowledges Ermenegildo Zegna for supporting her career and works through the Ermenegildo Zegna Founder's Scholarship 2018-2019 and 2019-2020. The funders had no role in study design, data collection and analysis, decision to publish or preparation of this specific manuscript.

Authors’ Contribution

M.F., F.R., G.A., N.V. Conceptualization; M.F, F.R., Methodology; M.F. Software; M.F. Validation; M.F. Formal analysis; M.F., F.R., G.A., N.V. Investigation; M.F., G.A. Resources; M.F., F.R., G.A., N.V. Data Curation; M.F., F.R., G.A., Writing - Original Draft; M.F., F.R., Writing - Review & Editing; M.F., Visualization; M.F., Supervision; M.F. Project administration; M.F., G.A. Funding acquisition; (the roles are assigned according to the Contributors Roles Taxonomy, CRediT)

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