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Technical Analysis of the Masonry of the Bargello' Palace, Florence (Italy)

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Featured Application: This paper establishes the assemblages, material and mechanical parameter of the Bargello' masonry; these data can be used for the seismic assessment of this historical building.

Abstract: This study defines the assemblage, materials, and mechanical parameter of the XIV century Bargello Palace at Florence (Italy). For this purpose, according to the rule in force, NDT and LDT had been performed on the Bargello walls, namely: direct observations, georadar, ultrasonic, thermic, DAC-test, and endoscopy. The results outline that the Bargello masonries are well done, as use in Florence in the XIV–XV centuries; they are solid walls, made in tightly sealed flat quoins, with external facing and internal plastering, and with a percentage of stones to mortar equal to about 70%. The results allow assigning of the Bargello's masonry to one of the categories provided by the rules in force, with the relative mechanical parameter values for the need of a seismic verification assessment.

Keywords: masonry; Bargello; technical analysis; NDT; LDT

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1. Introduction

The conservation of historical, cultural buildings is fundamental for ensuring the prolongation of their life and cultural witness of ancient culture and construction techniques; therefore, their conservation deserves special attention, because they are symbols of a culture and represent the local community as a whole. Usually they are under local, country, and UNESCO patronage and cannot be subject of invasive investigation.

These concepts have been the object of many international guidelines, called Restoration Charters (Table 1), which outline the procedure for a correct conservation path [1].

Table 1. Restoration Charters.

Restoration Charters
Athens Charter, 1931
Italian Charter for Restoration, 1932
Venice Charter, 1964
Italian Charter for Restoration, 1972
Amsterdam Charter, 1975
Washington Charter, 1987
Nara Document of Authenticity, 1994
Krakow Charter, 2000
ISO 13822-2010, 2010
ICOMOS Recommendation, 2010

Conservation of heritage buildings must preserve "Integrity" and "Authenticity" of the building, and "Vulnerability" must be reduced.

These themes had been addressed in the 3rd Int. Conf. on Techniques, Measurements & Materials in Art&Archaeology2018, held in Jerusalem (Israel) and in the AIPnD National Conference held in 2019 at Milan (Italy).

In Italy, the D.Lgs. 42/2004, art, 29, and the MIBAC 2011 "Guidelines rules for conservation of cultural heritage and the reduction of seismic risk for cultural heritage buildings" are in force. According to this Guidelines, the first step for a correct conservation work is the definition of the knowledge framework through the historical analysis, documents, geometry, and technical data. However, there is the necessity to acquire technical data on the masonry setting through non-destructive investigation techniques (NDT), such as photogrammetry, laser scan, thermography, georadar, sonic/ultrasonic tomography, Schmidt hammer, and seismic survey; or low destructive direct (LDT) inspections, such as DAC-Test, endoscopies, descaling of plasters, essays, small trenches, and flat-jack.

Due to the rules on force and in prevision of a seismic vulnerability assessment, the Bargello Palace at Florence (Figure 1), Italy, has recently been the subject of extensive restoration work of the external curtains and of the inside of the Magdalena Chapel; in this frame it was possible to execute some investigation for defining materials and structures of the wall curtain of the back yard.

Figure 1. (**a**) the Bargello palace at Florence (Italy); (**b**) in foreground the tower and the front wing, back the porticos, covered courtyard, the rear wing, and the Magdalena Chapel site; (**c**) the interior of the Magdalena Chapel and the east wall with mural paintings by Giotto.

This study follows other similar studies on the medieval masonries of outstanding Florentine monumental cultural heritage buildings [2–5], from which it summarizes the approach and its methodologies, that can now represent a reference standard for the application of NTD and LDT to future similar studies on ancient masonries.

2. Materials and Methods

The first step in the study of the masonry of an historical palace, in an ordinary lack of design data, is to define the historical context of its construction in order to have general references about traditional construction techniques and local material in use.

The Bargello Palace dates back to 1255 when people of Florence decided to build a palace suitable for all the Municipality administrative offices. The chosen areas were sites of private houses and plots; the Volognona tower of the Riccomanni family and a house of the Boscoli family became the nucleus of the new palace [6].

Between 1260 and 1280, a back area was incorporated in the Palace and provided with a porticoed courtyard; between 1316 and 1320, it was raised up to the present-day highness and on the inner porticos, new apartments and the Magdalena Chapel were built [7–9].

In 1574, the Palace became prisons and the law Court, under the chair of the *Bargello*, which was the name of the chief of the City Guards, from which the present historical name.

According to the Bargello Museum Administration and under the supervision of the Opificio delle Pietre Dure staff (OPD, a technical Institute of the Ministry of Culture for conservation works), NDT and LDT had been performed on the external walls of the back yard curtain, and inside the Magdalena Chapel, in order to define materials, assemblages, and technical properties of the masonry; descaling of plasters, essays, small trenches, and flat-jack had been not permitted by the local authority.

The Magdalena Chapel walls were the only ones inside the museum free from exposition due to the need of conservation works on the Giotto's frescos covering the walls.

Research and investigation activities were carried out according to the provisions of the [10], point 4.1.6 in:

NDT—Non-destructive investigations:

- Photogrammetric and laser scanner survey of the Magdalena Chapel and reconstruction of a 3D HBIM;
- Passive and active thermal investigations of the walls and vault, with image straightening and assembly in the 3D model;
- Sonic investigations of 11 areas of 1 × 1 m of the walls appropriately chosen in collaboration with the OPD restorers, and assembly in the 3D model;
- Detailed GPR (Ground Penetrating Radar) surveys for a total of 35 scan lines, four scan lines on the vault, and four detail sectors of 1 × 1 m suitably chosen in collaboration with the restorers of the OPD restores, and assembly in the 3D model.

LDT—Low-destructive investigations:

- Ten perforations of 12 mm in diameter and pushed up to 70 cm, the walls being 130 cm, with execution of DAC-Test and relief of cuttings, performed in positions agreed with the OPD restorers, and assembly in the 3D model;
- Endoscopic photo/video surveys in those drill-holes.

3. Results

The LDT investigations had been carried out on the external facades of the walls of the backyard of the Bargello taking advantage of the scaffolding in place; from here, DAC-Tests and endoscopic investigations were executed, whereas the NDT georadar and sonic surveys were carried out on the internal wall of the Magdalena Chapel. The external walls of the courtyard and rear wing had been built at the same time, therefore, the results from the Magdalena Chapel can be referred to all these masonries.

3.1. 3D HBIM

For the management and organization of the data collected during the diagnostic campaign, it was decided to create a 3D model of the chapel that would highlight the wall structure detected, as well as the location of the various surveys and their results in a single framework, according to the HBIM concepts.

Starting the survey from the point cloud provided by a laser scanner survey, a 3D model with solid elements was reconstructed using the BIM methodology. The 3D digital model was created in Revit (© AUTODESK) using parametric objects to which it was possible to link different types of information or links to external files.

Object-oriented modelling was developed by using system families for walls, floors, and roofs, and customized families for those relating to different types of investigations.

The photographic survey provided made it possible to obtain orthomosaics, which were applied to the surfaces of the model (Figure 2).

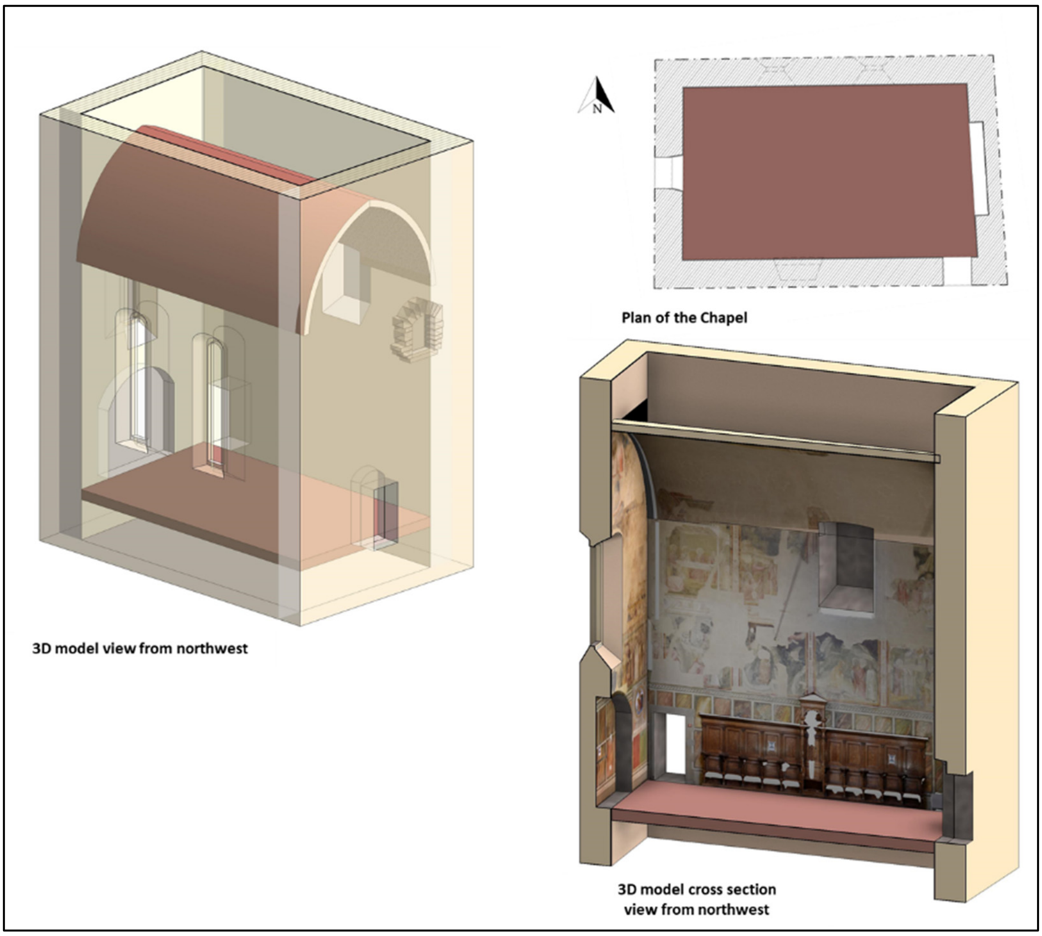

Figure 2. HBIM of the Magdalena Chapel plastered with the photo planes.

For each element modelled in 3D, it was possible to link data relating to dimensions, analysis results, materials, etc.

Each object has been provided with an ID that identifies it and which can be viewed using the appropriate label and within an abacus that allows the model to be interrogated.

It is possible to manage the visualization of the model through customized views and in the 3D environment through dynamic and exploded sections that facilitate the interrogation phase.

The result obtained is a digital twin of the building, which allows analysis of the results of the investigations in close relationship with the areas investigated and to identify and measure any anomalies found.

3.2. Masonry Assemblages

The walls of the Bargello appear well done, as is common for the Florentine buildings of that time [11]; they are thick, about two Florentine arms (about 130 cm), and are made with a double face of well-tightened quoins, with the external faces left *facciavista* at regular rows (Figure 3), and the internal plastered, window frames are marked by ashlars; the mortar layer's thickness is around 1 cm.

Figure 3. The Bargello palace at Florence (Italy), *facciavista* setting of the external facades, in regular rows of Pietraforte quoins and mortar layers of about 1 cm.

The stone used is Pietraforte, a quartz-calcareous arenaceous turbiditic sandstone, placed flat according to the bedding, in rows with a modal thickness of 15–30 cm. That is the modal thickness of the Pietraforte beds, provided from the quarries of the Costa (current Costa Scarpuccia and Costa San Giorgio) and of Montecucco (current area of Pitti Palace and Boboli Gardens) [12,13]. Technical physical–mechanical data for Pietraforte have been recently published [14] (Table 2).

Table 2. Pietraforte physical–mechanical data from [14].

Property	Value
Volume weight	26.25 kN/m^3
Ultrasonic Velocity	2455–3712 and 4751–5309 m/s
UCS	120 MPa
Porosity	2.6%
Imbibition coefficient	1.3–1.6%
Water absorption at atmospheric pressure	1.15–1.55%
Water absorption by capillarity	0.9–1.9 g/m^2/s$^{1/2}$

This masonry refers to the type "Stonemason techniques with quarry quoins placed on horizontal rows" [15].

The masonry of the vault of the Magdalena Chapel, is directly observable in the overvault, and, presumably, resembling that of all the vaults they built up at the same time; this vault is made of bricks of about 40 × 5 × 20 cm set on a head (Figure 4).

Figure 4. The Bargello palace at Florence (Italy): (**a**) the overvault of the Magdalena Chapel, the brick setting of the vault; (**b**) the plastered internal side of the walls, with the quoins setting visible in transparency.

Specific analysis on the mortar had not been done, but according to the literature [13,16–18], the quality and the mechanical data (Table 3) of the Florentine mortar of that time is well known: that it was consistent and strong with very good physical–mechanical properties. First, it was made by using the marbles from spolio of Roman buildings and then the Alberese limestone from Le Falle and Pontassieve (close east of Florence), and the excellent sands of the Arno River with predominantly quartz grains.

Table 3. Physical–mechanical data of the medieval mortar at Florence, by [3].

Property	Value
Volume weight	17.5 kN/m^3
UCS	19.6 MPa
σ_t	2.05 MPa
Young modulus	7.85 MPa
Poisson ratio	0.27
Porosity	28.2%

3.3. Sonic Survey

On the free walls of the Magdalena Chapel, a series of sonic surveys had been made in order to investigate the plaster–masonry connection and the overall quality of the masonry; the instrumentation used was Novasonic U5200 CSD from IMG Ultrasuoni srl.

As a whole, the resulted sonic velocities vary between a minimum of 429 m/s and a maximum of 2632 m/s, thus highlighting a diversified structure of the wall/plaster in different areas. This investigation revealed a few partial detachments of the plaster from the underlying masonry, slower speed areas, or the presence of cracks in the masonry (Figure 5). The resulting walls were constituted by full masonry with mixed materials.

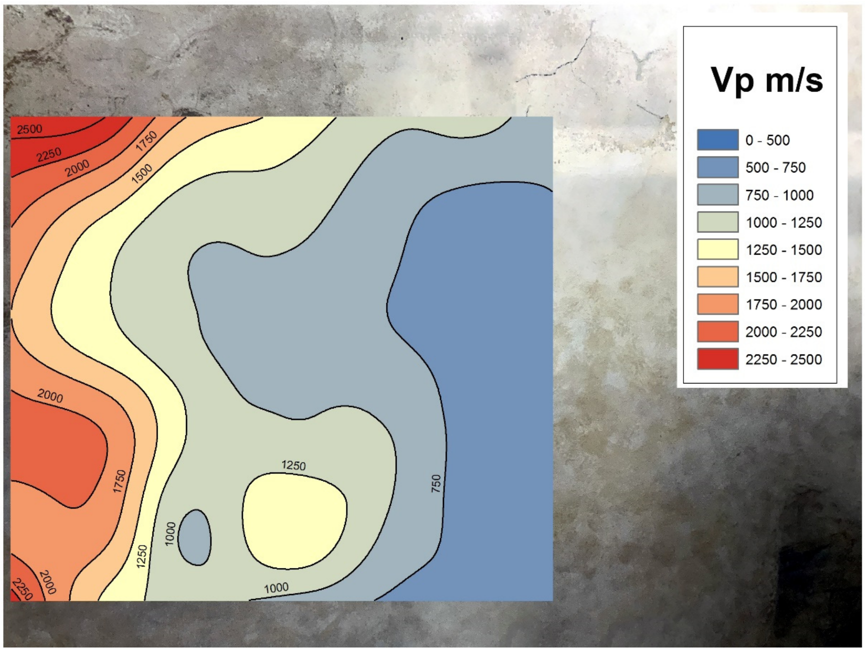

Figure 5. Example of the results from the sonic survey, implemented onto the photo plane; reds indicate high sonic velocity, and blues lower sonic velocity with probable plaster detachment from the behind masonry.

3.4. Ground Penetrating Radar Survey

As part of the scientific and technical cooperation between the Department of Earth Sciences and IDS-Georadar S.p.A. (Hexagon Group), a Ground Penetrating Radar (GPR) survey of the walls was carried out by means of C-Thrue georadar instrumentation.

GPR surveys consisted in both linear and detailed tomography investigations of specific areas (of about 1 × 1 m) according to the indications of the OPD restorers (Figure 6).

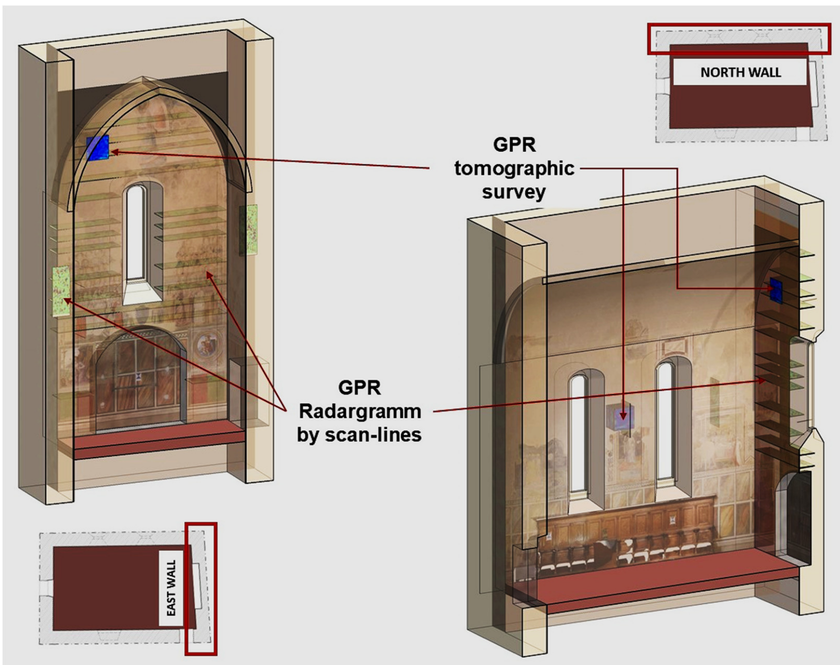

Figure 6. HBIM of the Magdalena Chapel plastered with the photo planes and reporting all the performed investigations in their proper spatial position: (**right**) east and north walls; and (**left**) south and west walls.

The investigations show the presence of a mixed and full masonry; in the Magdalena Chapel the presence of a buffered window has been detected (Figure 7), and near the window, the GPR signal evidenced the presence of angular quoins.

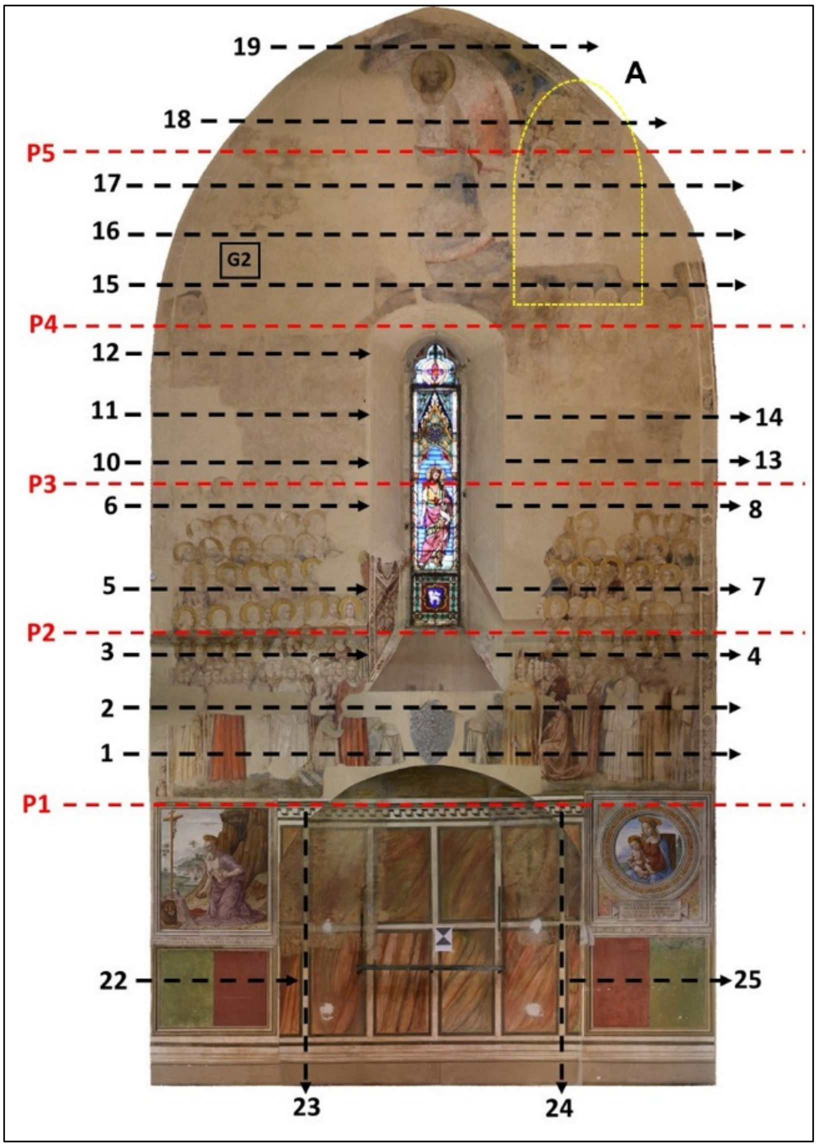

Figure 7. GPS scanlines (dotted black) on the east side of the Magdalena Chapel mounted on the HBIM (red dotted line being the scaffolding planes); A, trace of probable presence the closed window; P1→P5, scaffolding planes; and black numbers, GPR scan-lines.

3.5. Thermal Survey

Thermal survey, by Thermo camera FLIR T460, has been performed inside the buildings, in both passive and active mode; for the active mode, the heating was set to the top for 48 h.

The main results of the thermal investigations do not show particular anomalies, except the presence and extent of a damp spot in the upper part on the east wall of the Magdalena Chapel. Here, on the west and south walls, the traces of buffered openings at the level of a now-removed intermediate floor can be seen.

A thermal survey identified the presence of stone quoins or brick in the masonry and brick arches overhanging the openings (Figure 8).

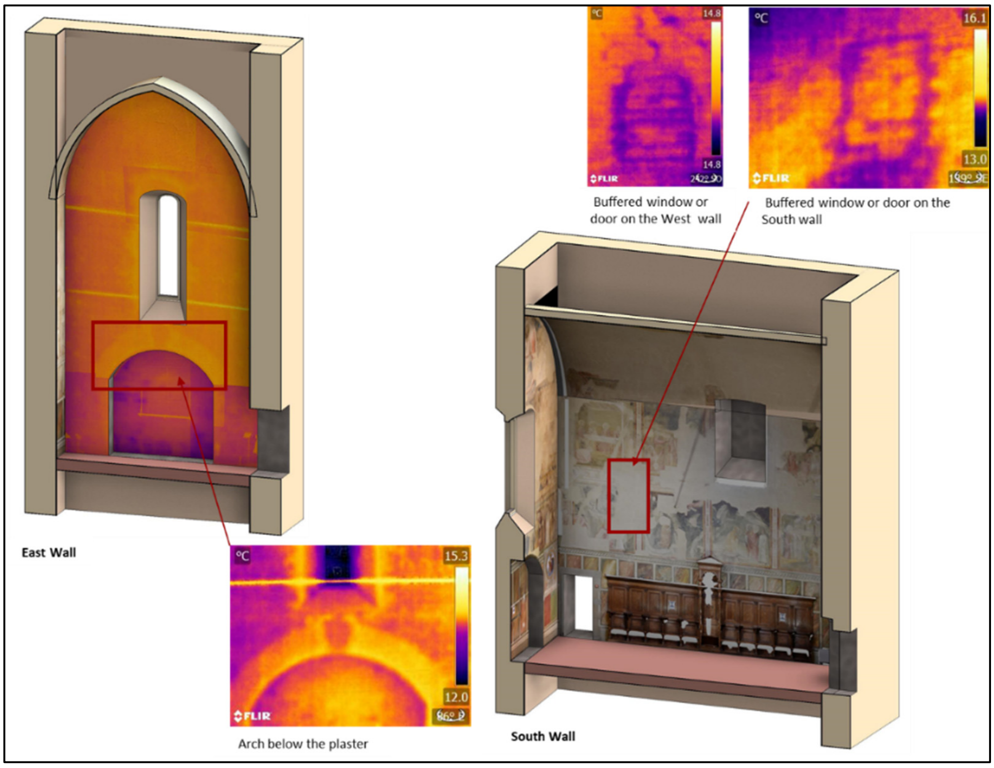

Figure 8. Thermo survey of the Magdalena Chapel; a closed window and the regular structure of the masonry by rows of regular quoins are well visible; on the right the temperature scale.

3.6. *DAC-Test*

The DAC-Test consists of controlled micro-perforations (12–16 mm ø), performed at constant pressure and speed, with analysis of the cutters to verify the consistency and materials of the masonry.

Drill-holes were made using the scaffolding mounted on the external side of the walls (Figure 9); in order to avoid any possibly damage on the fresco on the inner sides, walls thickness (≈130 cm) was determined in the windows shafts and, therefore, drill-holes had been limited to 70 cm.

Figure 9. DAC-test execution by the scaffolding; drill-holes were made in the mortar to save the quoins' integrity.

It allows the qualitative mapping of a wall by points, and can be used as calibration for more extensive GPR, sonic and thermal investigations.

3.7. Endoscopy

In the holes of the DAC-Test, once cleaned and refreshed, endoscopic video and photo recordings were carried out using micro-cameras equipped with illuminating LEDs and connected to a specific receiver.

This investigation allows a direct view of the inner structure and assemblages of the masonry and of the material in place (Figure 10).

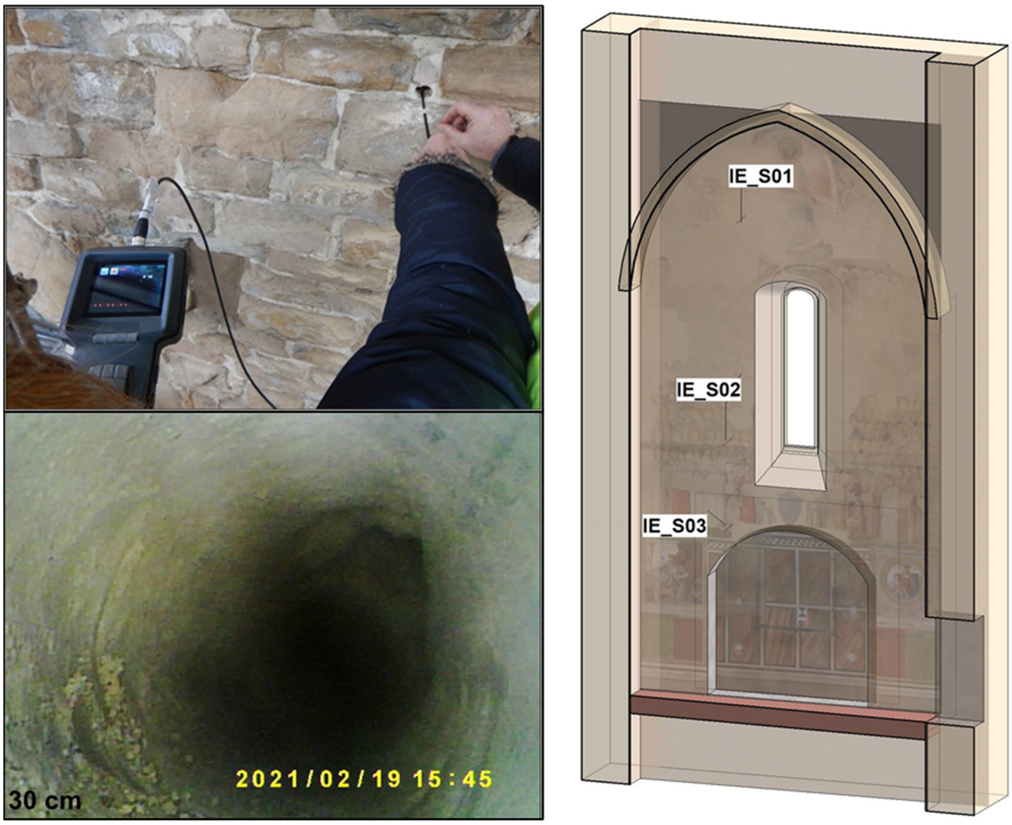

Figure 10. Endoscopy and a picture inside the wall at 30 cm from the outside surfaces. On the right, a view of the HBIM model with the position of the endoscopies.

Endoscopies allowed direct verification that the walls consist of external curtains of well-placed rows of Pietraforte stones in quoins about 20–30 cm thick, and a compact core of mortar and well compacted stone slices.

All the external curtains had been built at the same time; therefore, these assemblages can be considered uniform for all the Palace's external walls.

4. Discussion

The walls of the Bargello, Florentine walls of the XIV–XV centuries, appear well done; they are solid walls, made in tightly sealed flat quoins, with external facing and internal plastering.

The mise on place is for regular successive courses of quoins in rows for the thickness of the entire masonry, with the exposed face well prepared and behind a full bulk masonry with a ratio of stones to mortar equal to about 70%; the thickness of the mortar beds between the rows is about 1–2 cm; the masonry is reinforced by stone elements placed crosswise from the outside to the inside (diatons).

Compared to the Abacus of the historic walls of the Tuscany Region [19], these walls can be ascribed to Type B1AoMb "Squared stone walls with elements that are not homogeneous but well meshed in the longitudinal and transversal direction, good quality mortar", and in any case not with a sack but with full masonry (Figure 11).

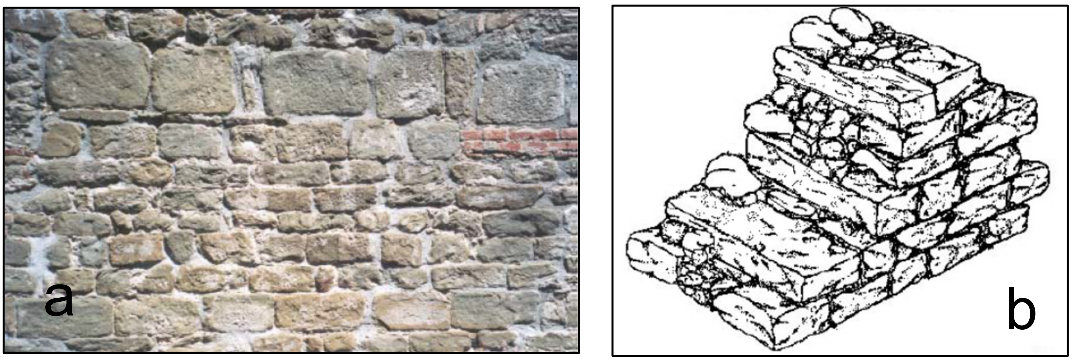

Figure 11. Example of the B type masonry assemblage from [19] abacus; (**a**) external assemblage; (**b**) inner assemblages.

With reference to Table C8A.2.1 of [16], these walls are in Category II "Wall with hewn segments with limited thickness and internal core"; the relative reference values for the mechanical parameters of this type of masonry are here reported; these values are to be corrected according to the state of maintenance of the masonry, which for the Bargello is excellent and, therefore, they are to be increased according to Table C8A.2.2 of [16] (Table 4).

Table 4. The Bargello's masonry physical–mechanical data according to Table C8A.2.1 and Table C8A.2.2 of [20].

Masonry Category	***f*/*m*** **N/cm²**	**T_0 N/cm²**	**E N/mm²**	**G N/mm²**	**w kN/m³**
II	200–300	3.5–5.1	1020–1440	340–480	20
Maintenance	Mortar quality	Joint < 10 mm	Registrations and appeals	Diacroni	Nucleus quality
Very good	1.4	1.2	1.2	1.5	0.8

5. Conclusions

For the investigation of the Bargello's masonry, many techniques had been applied: GPR, thermography, ultrasonic, DAC-test, endoscopy, and the result located in a full HBIM 3D model for a better understanding.

GPR results appear to be the best performing, but it requires DAC-Test and endoscopy for calibration, in the same relationship as between boreholes and seismic line survey.

Thermography can give a good figure of the masonry assemblage close to the investigate surface, but it needs the wall to have a thermal release towards the outside, that can occur in autumn when the heating accumulated in the wall during summer is released to the outside, or after a forced artificial heating.

Sonic investigation only gives results about the local condition of the continuity between plaster and masonry or for the presence of a fracture in the masonry below the plaster.

Nevertheless, previous knowledge about historical masonry and its evolution through the time [21–24] is necessary for collecting all these technical data into a reliable model of the investigate masonry, as recently conducted for others historical buildings at Florence [25,26]

Regarding the Bargello masonry, it is of the beginning of the XIV century, when the masonry techniques, resumed from the IX century and gradually evolved, had reached a very good standard, as demonstrated by the many towers, and religious and civil buildings built up at Florence in those times and still standing up in good conservation conditions [27].

At those times, the technical-constructive knowledge was in the hands of various families of master masons who worked both in their city of origin and moving between cities following the construction sites with the most appeal and economic return; in this regard, Florence was one of the flowering areas of this knowledge and for its application [28].

The researchers on the Bargello's masonry confirm the high technical level of the master masons involved in its construction; equally, the research results allow the referral of the Bargello' masonry to one of the categories provided by [16] with the relative mechanical parameters values for the seismic verification assessment.

This approach also underlines the importance of a 3D HBIM model on which to correctly position all the investigations performed. The BIM methodology is, therefore, a valid tool for creating an active database that allows one to simultaneously read all the information relating to an element in order to identify critical issues and provide conservation strategies through multidisciplinary knowledge.

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References

1. Coli, M.; Iwasaki, Y. Novel Approaches and Technologies for Heritage Buildings Conservation: Editorial. *Appl. Sci.* **2021**, *11*, 10597. [CrossRef]
2. Coli, M. I materiali della Cupola del Brunelleschi: Osservazioni e riprese video nei fori di sondaggio della cupola interna. In *Il Monitoraggio Delle Grandi Fabbriche Storiche*; Mandragora: Firenze, Italy, 2012; pp. 130–141.
3. Garzonio, C.A.; Cantisani, E.; Coli, M.; Cuzman, O.; De Luca, D.; Lubrito, C.; Ricci, M.; Vettori, S.; Sibilia, E. I materiali costitutivi del Battistero. In *Il Battistero di San Giovanni, Conoscenza, Diagnostica, Conservazione*; Gurrieri, F., Ed.; Mandragora: Firenze, Italy, 2017; pp. 179–191. ISBN 978-88-7461-323-6.
4. Coli, M.; Papeschi, P.; Boscagli, F.; Innocenti, L.; Agostini, B. *GPR Investigation on the Masonry of the Brunelleschi's Cupola, Florence (Italy)*; Giornale Delle Prove Non Distruttive, Monitoraggio, Diagnostica; AIPnD: Brescia, Italy, 2018; pp. 52–57. ISSN 1721-7075.
5. Coli, M.; Innocenti, L.; Castellini, M. Indagini non invasive sulle murature. In *La Sala Grande di Palazzo Vecchio e la Battaglia di Anghiari di Leonardo da Vinci, Dalla Configurazione Architettonica all'apparato Decorativo*; Barsanti, R., Belli, G., Ferretti, E., Frosinini, C., Eds.; Leo, S. Olschki.: Firenze, Italy, 2019; pp. 371–381. ISBN 978 88 222 6670 5.
6. Vannucci, M. *Splendidi Palazzi di Firenze, Le Lettere*; Casa Editrice Le Lettere: Firenze, Italy, 1995; ISBN 88-7166-230-X.
7. Giorgi, L.; Matracchi, P. Il Bargello a Firenze. Da Palazzo del Podestà a Museo Nazionale. In *Santa Maria del Fiore. Teorie e Storie Dell'archeologia e del Restauro Nella Città Delle Fabbriche Arnolfiane, Rocchi Coopmans de Yoldi, G.*; Alinea: Firenze, Italy, 2006; pp. 125–173. ISBN 8881259079.
8. Giorgi, L.; Matracchi, P. *Il Bargello di Firenze. Nuove indagini sulla costruzione del palazzo, In La Storia del Bargello*; Paolozzi strozzi, B., Ed.; Silvana Editoriale: Firenze, Italy, 2004; pp. 95–113. ISBN 9788882158477.
9. Yunn, A. *The Bargello Palace, the Invention if Civic Architecture in Florence*; Harvey Miller: London, UK, 2015; 242p, ISBN 978-1-909400-31-3.

10. MIBACT, Linee Guida per la Valutazione e Riduzione del Rischio Sismico del Patrimonio Culturale Allineate Alle Nuove Norme Tecniche per le Costruzioni, D.M. 14 Gennaio 2008. 2011. Available online: https://www.google.it/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjShryvhMP1AhWM_7sIHYV_BnkQFnoECBsQAQ&url=https%3A%2F%2Fwww.beniculturali.it%2Fmibac%2Fmultimedia%2FMiBAC%2Fdocuments%2F1295444865088_LINEE.pdf&usg=AOvVaw0ypJKirGucI4lhx6QvnHRo (accessed on 1 January 2022).
11. Giovannini, P. L'apparato murario e il rivestimento interno del piano terra e del matroneo. Materiali, tecniche di lavorazione e caratteristiche di messa in opera. In *Santa Maria del Fiore—Piazza, Battistero, Campanile*; Rocchi, G., Ed.; Coopmans de Yoldi, Università degli Studi di Firenze, Dipartimento di Architettura, Il Torchio: Firenze, Italy, 1996; pp. 72–96.
12. Coli, M. The Boboli Garden, Firenze (Italy): From quarryscape to place of delights. In *Natural Stone for Cultural Heritage: Local Resources with a Global Impact, International Conference on "Natural Stone for Cultural Heritage: Local Resources with a Global Impact", Abstract Book*; Prikryl, R., Ed.; Charles University: Prague, Czech Republic, 19–22 September 2017; pp. 1–13.
13. Coli, M.; Donigaglia, T.; Tanganelli, M. *Historical Construction Materials at Firenze (Italy): A Selected Supply at km 0. REUSO 2018, L'intreccio dei Saperi per Rispettare il Passato Interpretare il Presente Salvaguardare il Futuro*; Minutoli, F., Ed.; Gangemi: Roma, Italy, 2018; pp. 1353–1362. ISBN 978-88-492-3659-0.
14. Coli, M.; Donigaglia, T.; Cristofaro, M.T.; Tanganelli, M.; Viti, S. The "Pietraforte" of the Historical Buildings of Florence (Italy): Geology and Technical Assessments. *Case Stud. Constr. Mater.* **2022**, *in press*.
15. Bianchi, G. *Costruire in Pietra Nella Toscana Medievale. Tecniche Murarie dei Secoli VIII—Inizio XII, Archeologia Medievale, XXXV*; All'Insegna del Giglio: Firenze, Italy, 2008; pp. 23–38. ISBN 978-88-7814-382-1.
16. Barbi, L.; Leggeri, B.; Vasari, V.; Franchi, R.; Fratini, F.; Manganelli Del Fa, C. *Indagine Sperimentale Sui Materiali Costituenti la Cupola di Santa Maria del Fiore*; Università di Firenze, Facoltà Architettura, Atti Dipartimento di Costruzioni: Firenze, Italy, 1986; pp. 5–78.
17. Pecchioni, E.; Fratini, F.; Cantisani, E. *Atlante Delle Malte Antiche in Sezione Sottile al Microscopio Ottico, Collana Atlanti Della Conservazione del Patrimonio Culturale*; Nardini Editore: Firenze, Italy, 2014; 78p.
18. Pecchioni, E.; Fratini, F.; Cantisani, E. *Le Malte Antiche e Moderne: Tra Tradizione ed Innovazione. II*; Pàtron Editore: Parma, Italy, 2018; 80p.
19. Regione Toscana, Servizio Sismico Regionale, Rilevamento Della Vulnerabilità Sismica Degli Edifici in Muratura; Firenze, Italy, 2003; 87p. Available online: https://www.regione.toscana.it/documents/10180/12262198/vsm_man.pdf/095d3648-191d-43aa-ae88-ad78cff79fb3 (accessed on 1 January 2022).
20. CIRCOLARE 2 Febbraio 2009, n. 617 Istruzioni per L'applicazione Delle «Nuove Norme Tecniche per le Costruzioni» di cui al Decreto Ministeriale 14 Gennaio 2008, GU n. 47 del 26-2-2009—Suppl. Ordinario n.27. Available online: https://www.gazzettaufficiale.it/eli/id/2009/02/26/09A01318/sg (accessed on 1 January 2022).
21. Pollione Vitruvio, M. *L'Architettura di Marco Vitruvio Pollione, Tradotta e Commentate dal Marchese Berardo Galliani*; Fratelli Terres, Ristampa Anastatica Antiche Fornaci Giorgi: Napoli, Italy, 1790; p. 393.
22. Rondelet, G. *Trattato Teorico e Pratico Dell'arte di Edificare. Prima Traduzione Italiana Sulla Sesta Edizione Originale con Note e Giunte Importantissime per Cura di Basilio Soresina L.* Caranenti: Mantova, Italy, 1881. Available online: http://risorseelettroniche.biblio.polimi.it/rondelet/cd/index2.htm (accessed on 1 January 2022).
23. Vitry, U. *Il Proprietario Architetto*; Paolo Lampato: Venezia, Italy, 1931; p. 180.
24. Diderot, D.; D'alambert, J. *Enciclopedia o Dizionario Ragionato Delle Scienze, Delle Arti e dei Mestieri Ordinato da Diderot e D'alembert*; Oscar Mondadori: Milano, Italy, 2003.
25. Coli, M.; Donigaglia, T.; Papeschi, P.; Boscagli, F.; Agostini, B.; Caselli, G. GPR application for NDT investigations on the Cultural Heritage Monumental Buildings of Florence (Italy). *J. Civ. Eng. Archit.* **2019**, *13*, 415–426. [CrossRef]
26. Cardinali, V.; Castellini, M.; Cristofaro, M.T.; Lacanna, G.; Coli, M.; De Stefano, M.; Tanganelli, M. Integrated techniques for the structural assessment of cultural heritage masonry buildings: Application to Palazzo Cocchi Serristori in Florence. *J. Cult. Herit. Manag. Sustain. Dev.* **2021**, *23*. [CrossRef]
27. Bargellini, P.; Guarnieri, E. *Firenze Delle Torri*; Bonechi: Firenze, Italy, 1973; 230p.
28. Terenzi, P. *Maestranze locali e maestranze forestiere nell'Italia Medievale, In Le Pietre Delle Città Medievali*; Basso, E., Bernardi, P., Pinto, G., Eds.; Centro Internazionale di Studi sugli Insediamenti Medievali: Bologna, Italy, 2020; pp. 25–46.