

Article

An Unconventional Field Mapping Application: A Complete Opensource Workflow Solution Applied to Lithological Mapping of the Coatings of Cultural Heritage

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Abstract: The conservation of a primary importance historical building requires organization, management, continuous updating, comparison, and visualization of a large amount of data of different nature and origin. In relation to these aspects the use of a GIS brings various advantages including single and univocal management of the entire amount of existing data in a relational, dynamic, updatable and queryable way. The integration of a mobile solution permits the updating of the dataset and checking on site all information. The workflow presented uses opensource solutions, desktop and mobile, which allows the creation of an unconventional lithological Field Mapping activity: starting from photo interpretation and in situ survey, all the coating materials (stone, etc.) of some monuments of primary historical and cultural interest have been mapped (i.e., Duomo di Firenze, Duomo di Prato). The product can be considered as a lithological cartography, vertically oriented, processed by field surveys, geognostic surveys and photo interpretation. All combined to create a “lithological” mapping of the coatings of the various monuments; the advantage is a new approach for conservation and restoration of Cultural Heritage. The proposed workflow involves a mobile solution, opensource, that allows the verification and management of the database in the field.

Keywords: cultural heritage; geological field mapping; qgis; qfield; geomatics for cultural heritage



Citation: Iandelli, N.; Coli, M.; Donigaglia, T.; Ciuffreda, A.L. An Unconventional Field Mapping Application: A Complete Opensource Workflow Solution Applied to Lithological Mapping of the Coatings of Cultural Heritage. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 357. <https://doi.org/10.3390/ijgi10060357>

Academic Editors: Mauro De Donatis and Wolfgang Kainz

Received: 13 April 2021
Accepted: 19 May 2021
Published: 22 May 2021

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1. Introduction

The UNESCO Convention Concerning the Protection of the World Heritage [1], divides heritage into cultural and natural heritage. Physical objects, such as monuments, architectural buildings, sculptures, paintings and archeological sites, are considered as Cultural Heritage.

Preventive conservation can be considered as the most efficient approach for maintaining and protecting heritage buildings and sites [2–4]; in particular, the conservation of a primary importance stone building, of Cultural Heritage relevance, requires organization, management, continuous updating, comparison, and visualization of a large amount of data, of different nature and origin.

What is presented in this article is a workflow, which is proposed as a good practice for the creation of a relational digital archiving system applied to the knowledge acquired on the stone materials of the external coating of some monuments of international interest (Firenze city center, UNESCO heritage site).

Therefore, in a context of preserving the Cultural Heritage, the proposed process aims to improve the knowledge of the current state of the monuments and be useful as a basis for future monitoring, maintenance, knowledge and usability activities.

The integration of information from different inspection and diagnosis techniques is reached through geoinformatics, a discipline that includes different data acquisition methods, such as laser scanning, photogrammetry and remote sensing, and many authors

promote the use of geoinformation approaches, for preserving the Cultural Heritage, with Geographical Information System (GIS) [5–7].

The first effect of the closure of the activities due to COVID-19 is the considerable acceleration of the digitization processes that has also affected the Cultural Heritage with the spread of museum “virtual tours”. This way of using Cultural Heritage had a very positive response among visitors.

Therefore, the development of cultural digital content can represent an opportunity to review many aspects of the conservation and use of Cultural Heritage in the future to create more synergistic links with visitors.

The choice of using a Geographic Information System [6,7] for the management of the state of knowledge on the external coating of an historic stone building of primary importance lies, first of all, in the extreme versatility of the GIS platform for the representation and analysis of oriented geometry in space, at any scale; secondly, in the possibility of updating and implementing the database that is being built in the various phases of development of the activity; thirdly, in the storage capacity and, consequently, in the simplicity of recovery and unitary management, of a large amount of data of different nature (Figure 1).

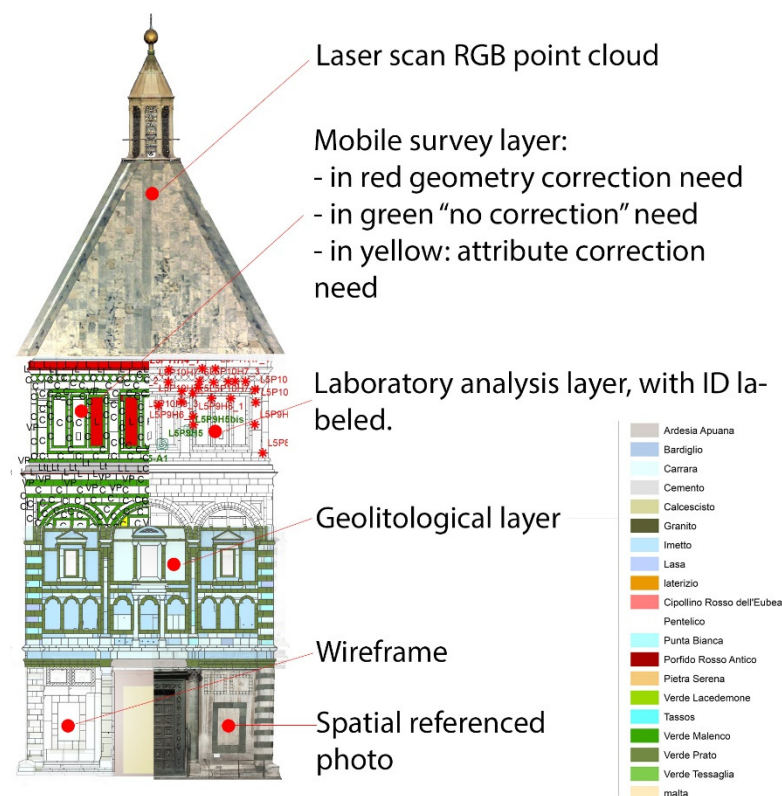


Figure 1. Example of the integration make possible with GIS/SIS software.

The proposed workflow is definable a “Spatial Information System” [8] and was applied to three different monuments in order to test its performance: the Battistero di San Giovanni, the Campanile di Giotto and the Duomo di Prato. All these three historical buildings are collocated in central Tuscany, Italy. The product can be considered as a lithological cartography, vertically oriented, processed by field surveys, geognostic surveys and photo interpretation. All combined to create a “lithological” mapping of the stone coatings of the various monuments. The proposed field survey can be considered “unusual”, in sense that GIS tools applied, (such as QField or Input APP as we will see later) which are normally used to carry out geological, geomorphological surveys and to collect spatial data, are used in an innovative way, as a field data collector on a vertically oriented plane. The main objective was to create and test a complete system that would allow the creation

and updating of a database on the historic building, representing a new tool available to those responsible for the management, maintenance and care of the Cultural Heritage.

2. Materials and Methods

Compared to what is presented in the [5–7] works, the proposed workflow combines the use of different open source applications, demonstrating their versatility and opening new ways for their application.

The workflow here (Figure 2) is set up by three consequential macro-phases that have allowed the achievement of the objectives.

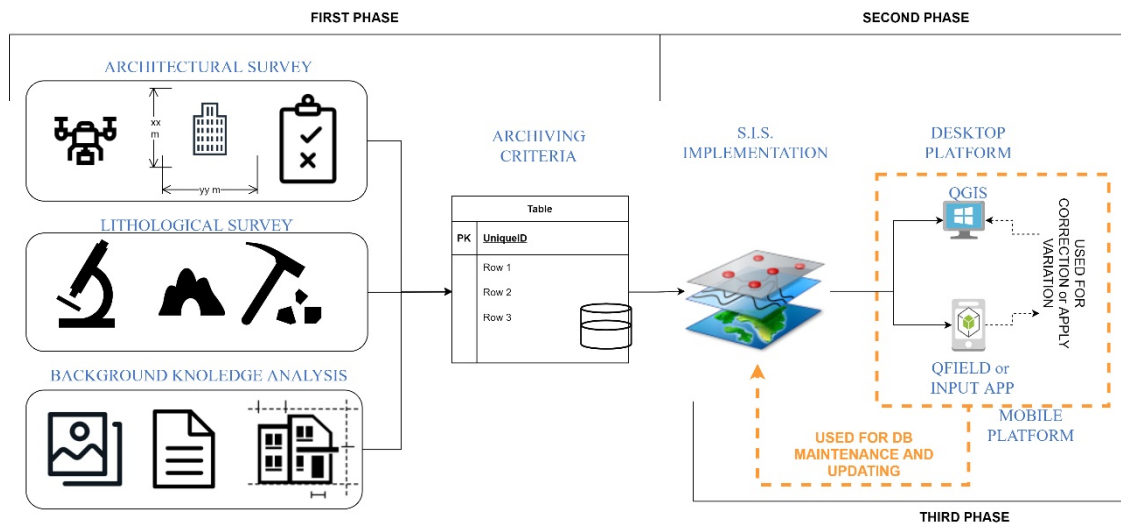


Figure 2. General workflow schema.

(1) First Phase

- (a) Analysis of the previous information assets.
- (b) Planning of survey campaign.
- (c) Lithological survey and analysis of materials.
- (d) Definition of archiving criteria and procedures.
- (e) Choice of desktop and mobile platform.

(2) Second Phase:

- (a) Implementation of the information system (desktop).
- (b) Implementation of the monitoring and updating tool (mobile).

(3) Third Phase:

Verification and testing.

2.1. First Phase

(a) Analysis of the previous information assets

The first phase is of fundamental importance and is linked to understanding the types, characteristics, and criticalities of the data, which is functional to the implementation of the information system. The available data, in relation above all to the complexity and importance of the monument and the conservation actions carried out over the centuries, are often very heterogeneous, numerous and characterized by different methods of management and organization, formats and encodings.

In line with the procedures that have always been used for the management of data on historic buildings from the architectural world, the first phase consists of the search for previous data, which can be of different nature and origin: historical archive data, such as historical images and annotations of surveys and interventions of various kind, carried out over the years; thematic raster, vector and CAD data, and drawings to be

recovered from the person who manages the assets. All recovered data must be digitized and/or computerized.

(b) Planning of survey campaign (if not present).

After the analysis of the previous information assets, an accurate survey campaign of the building must be designed. The aim is to obtain a geometrically correct and metric representation of the research object, which allows modelling through three-dimensional or two-dimensional.

The new technologies relating to geomatics, photography and information technology offer significant application for the documentation of Cultural Heritage, as regards the data acquisition and the representation phases, dissemination and multimedia communication [9]. These technologies have flanked the traditional “direct survey” [10], thanks to the advantage of a digital survey: greater precision and higher speed surveys than the traditional ones.

The modern technologies allow the integration of 3D models realised with active sensors (laser scanner) and other models derived from aerial and terrestrial photogrammetry. It is the combination of image-based methodologies and range-based modelling in a way that allows the visualisation of the artifact on different levels: starting from artwork, that requires high quality resolution to allow a detailed vision of every features and the state of preservation, until the building or the architectural complex that needs an accurate survey to gain its architectural and structural morphology, and the geometric and geographic context.

The modern Terrestrial Laser Scanner (TLS) acquired millions of points in a short time with the possibility to associate them to the colour information, recorded by the sensor itself or by an integrated external digital photo camera.

The combination of aerial photogrammetry from UAV and terrestrial photogrammetry from photo camera, allows to reconstruct the morphology of the territory and process high-resolution photos in order to acquire detailed information of the structures and the state of conservation of the materials.

In the literature, there are several examples of applications of a similar workflow [11,12], to obtain a mapping of the cracked structure and masonry deformations, or to analyse and conduct the results obtained by TLS and photogrammetry, highlighting the advantages and the limitations offered by their use [13].

A carefully planned survey campaign has as a final result a cloud of points which provided all the information on the geometries and distances of the external and internal visible elements of the building, which can be consulted in 3D and searchable, which can be used as a basis for 2D and 3D reconstructions.

(c) Lithological survey and analysis of materials

When studying a monument, we cannot ignore the analysis of the stone materials with which it is made. The study of these materials represents a window into the culture, the technical level and the knowledge of that era and therefore expands the historical and cultural value of a society, a civilization and a city. Behind each stone-built and monument, there is a quarry of provenance that involves a complex work cycle [14].

In the study of stone materials in place on a specific building or monument, there is no unique and certain way to determine the type of stone materials used, but there are three different types of approach to determine the type of material used and sometimes even its origin:

- Organoleptic analysis carried out by experts based on their knowledge and concerning grain, texture and warp.
- Documentary analysis carried out on archives and historical texts that report orders, origin and type of materials.
- Technical analysis of petrographic, mineralogical, geochemical and isotopic order, which on the basis of international databases, allow to attribute the analyzed sample to that particular lithotype.

Therefore, it is clear that more accurate attribution of the material occurs only when more of these approaches concur in a unique attribution.

In the proposed work the different materials were analyzed, mostly of all, through organoleptic analysis by an expert of historical stones of the territory; the expert is a figure who, in addition to the basic geological knowledge, must have knowledge concerning the history of the building under investigation, the historical period of construction, the quarries active at the time from which the material and the commercial context of the time was extracted. Despite all this, it is exceedingly difficult to trace the commercial name of the material and, sometimes, it is only possible to stop at the lithotype.

The characteristic of the stones used in the historical architecture of the Tuscany region, in particular the city of Florence and the surrounding area, are described accurately in some papers [15–19].

The building and coating materials recognized are mostly Pietra Serena, Pietraforte, Carrara Marble, Verde Prato and Rosso Cintoia. All these materials were taken from local quarries [15–20], located near the city; in addition to these, however, materials were also purchased from different parts of the world to increase the value of the historic building and/or monument. A particular case is represented by the Baptistery of San Giovanni, of the XII century, where many marbles from spolia of Roman buildings in Fiesole, a little town near Firenze, are on place [18].

The typical characteristics of materials mainly used in Tuscan architecture are widely described in the literature [17] and, thanks to these descriptions, following the observation of granulometry (grain size), texture (ratio of grains to crystals) and warp, the expert of the historical stones, following a stone-by-stone analysis of the individual buildings, was able to recognize the materials used for the Giotto's Bell Tower and the Cathedral of Prato.

Parallel to this type of analysis, a documentary research was also made, aimed at knowing any interventions carried out on the buildings in the past. These interventions can be of a different nature: interventions aimed at determining the degree of degradation of the materials; interventions to replace deteriorated materials and therefore risky for humans; restoration interventions [21].

Non-Destructive Techniques (NDTs) have been used on monuments of great historical importance, aimed at not affecting the integrity of the artifact, but at the same time particularly useful. Some examples of these analyses can be Georadar campaigns [22] on the slabs of monuments, to know their thickness, surveys with the cover meter aimed at knowing the correct position of the iron pins behind the slabs, and ultrasonic and Schmidt hammer tests in order to define the mechanical properties of materials and the weathering state of building stones [21–24]. This type of analysis can be very useful, for example, to plan replacement campaigns for damaged slabs, allowing for greater knowledge of them.

All this information is entered into the information system through the different possibilities typical of GIS software. Where possible they are inserted as data (numerical values or descriptive fields), where it is not possible to extract the information from the context or for more structured information (as in the case of specialist reports) they are inserted as hyperlinks.

(d) Definition of archiving criteria and procedures

Object modelling

In a GIS logic it is necessary to try to understand the meaning of the various object present on the graphic returns, to able to define classes of objects and represent them adequately with the available computer tools and geometric primitives.

Reference system

The peculiarity of GIS system is to manage vector data within geographic reference system [25], in the proposed Workflow, the concept of a geographical reference system was forced, rotating the plane and using a system composed of plane coordinates xz , with the x set to an arbitrary zero and the z considered as the effective altitude above the sea level generated by the rotation of normal Cartesian xy plane, where the values of the relevant z component are actually reproduced on y .

This reference point is a planimetric reference point (framed into a geographical reference system and different for each monument). Starting from this point all GIS layers (wireframe, photos, etc.) of the various monuments are “developed”, on a plane that is the rotation of the xy plane as described before.

All the data were located and digitized at the nominal scale of 1:10, to obtain a graphic error estimated at 0.2/0.3 cm. This value guarantees a high level of precision and accuracy in the measurements that can be carried out on the project and which allows high overall quality standards as well as maintaining low tolerance levels in topological checks.

“The basic element”

The basic element is the reference element to which to refer any data and/or information from the archive or of new generation. The basic element is characterized by a geometric simplicity, is present in several “clones” throughout the area of interest (e.g., facade of a building) and represents the basis on which to work. This is chosen because of the nature of the material and for reasons related to the architectural and structural characteristics of the artefact.

The basic element for the Battistero di San Giovanni and the Campanile di Giotto is the “lastra” (slab), while for Duomo di Prato is the “concio” (quoin). The differences between “lastra” and “concio” are that the “lastra” has a reduced thickness and is usually rectangular, with flat faces, generally used in construction as a coating for walls, building facades, floors; the “concio”, on the other hand, is a squared stone block used for construction, that also acts as “facciavista” element.

Other features

On the façade there are also other types of elements that are mapped, such as such as columns, or statues, friezes, decorations, mosaics. Each of these elements is reported in a dedicated shapefile with specific attributes.

(e) Choice of desktop and mobile platform

For the implementation of the Geographic Information System on the desktop side, we opted for the most widespread open-source solution available: QGIS.

QGIS is a free and open-source cross-platform desktop geographic information system (GIS) application that supports viewing, editing, and analysis of geospatial data [26].

QGIS supports many file types such as: shapefiles, coverages, personal geodatabases, .dxf, MapInfo, PostGIS. Moreover, QGIS should be integrated with other open-source GIS packages and Plugins to extend its capabilities. Among the features present in QGIS, a screenshot of QGIS project is displayed in Figure 3, is that of being able to manage hyperlinks to external files (e.g., pdf or images).

For the mobile side, two solutions were tested: QFIELD and INPUT APP/MERGIN. The first one is a solution based on Android app integrated with QGIS Plugin developed by OPENGIS.ch (2019). The app allows to efficiently work on GIS data outdoor, is an opensource project. The second is a free and opensource built on top of QGIS for collecting data, composed by two parts: a mobile app project (available for Android and iOS) to collect data and a webservice for data synchronization for collaborative managing of data.

The same platforms have been used in some reference works [8–27].

2.2. Second Phase

(a) Implementation of the information system.

Desktop side

All native vector files available in different formats, mainly *.dwg or *.dxf, have been converted to shapefiles and “moved to” a reference starting point, this point with geographics coordinates in real world, represent the “reference point”. All other data and spatial information (surveys, drawings, etc.) of the original document have been scanned in raster format, *.jpg or *.tif and “georeferenced” using as a reference base a vector wireframe extract from a photo-plane (or pre-existing or made ad hoc).

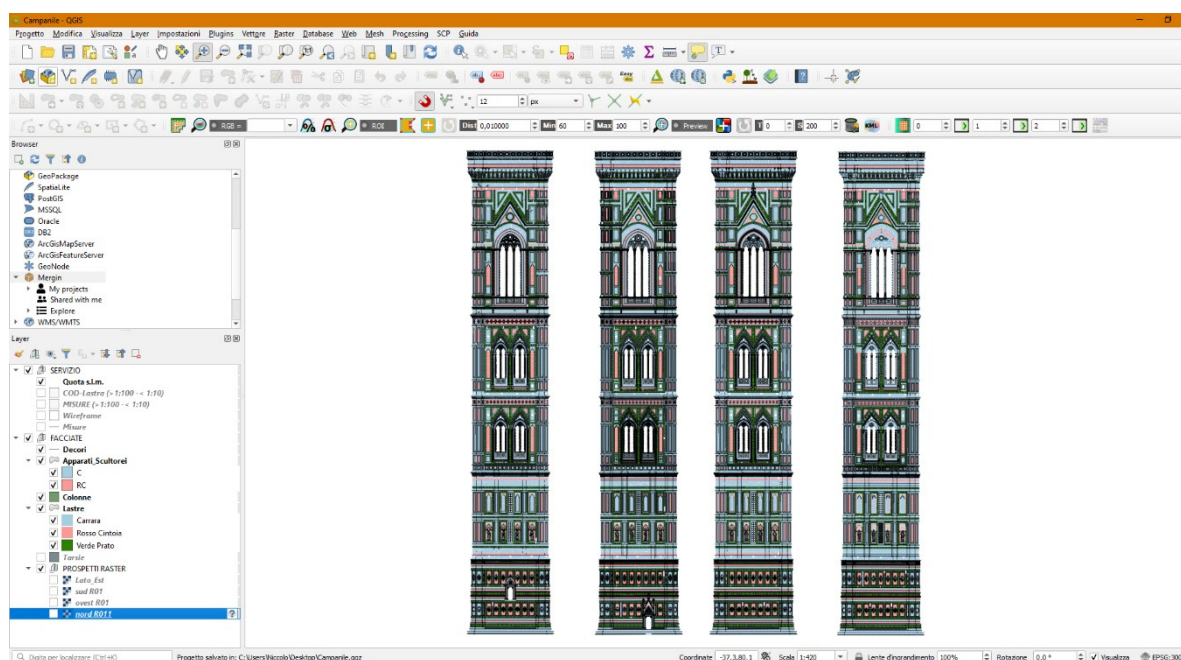


Figure 3. QGIS’s project of Giotto’s Campanile.

The implementation process of the information system is presented in Figure 4.

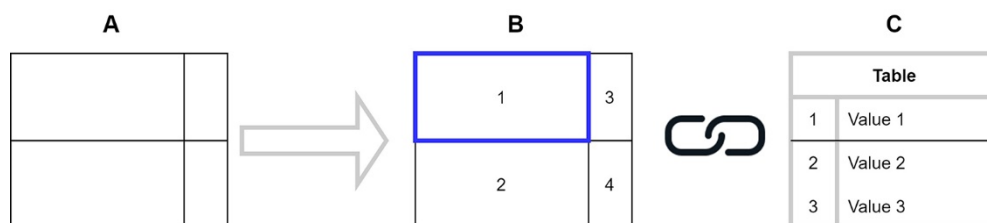


Figure 4. Base element extraction schema: A – vector wireframe; B – identification of base element on wireframe and assign ID; C – joining base element with table in database by ID field.

Starting from wireframe (A) realized as describe before, every single base element was “extracted” (B) from wireframe to generate a single element and associated with a basic element category in a table (“lastra” or “concio”, other material, artefacts or element). After this operation every base element is “named” by assigning an ID and filled the specific fields (C). The base element now is a GIS object, a polygon topologically correct and a tuple in a database.

The shape extraction process is carried out using the typical tools of GIS software, manually, to ensure the correspondence between photoplan, wireframe and generated geometric object.

The layer obtained then passes through the tools for correcting and verifying the topology and geometry.

To complete the information retrieved, other layers are inserted, each of which represents a defined set of elements referable to geometric objects recognized on the photoplan and forming part of the building. The diagram below (Figure 5) displays the archiving criteria referred to the Battistero di San Giovanni. In addition to the basic element “lastra”, with his specific related levels (lesioni/fractures, tracce/working sign, intarsi/inlays) there are: other materials (altri materiali), decorations (decorazioni), brackets (staffe), mosaics (mosaici), each with their own descriptive fields.

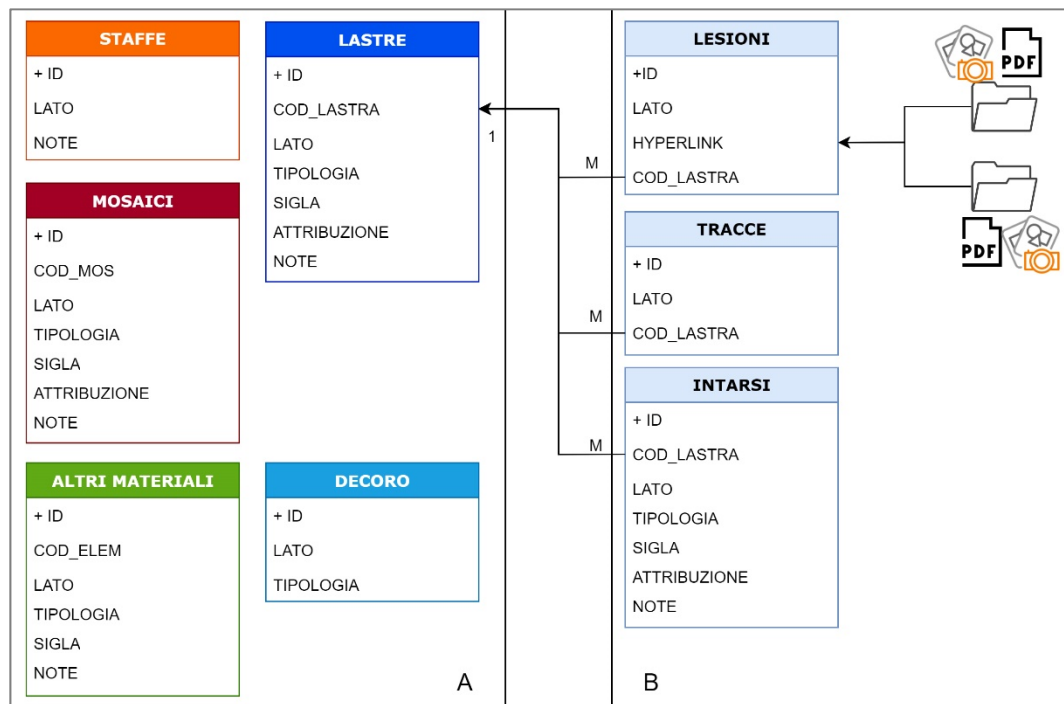


Figure 5. Information System Schema referred to Battistero. (A) Polygon layers; (B) layers referred to base element “lastra”, relation one to many.

The implemented data in the GIS system have been managed and organized within a series of “group layers” functional to the needs of data visualization and consultation, for example, the dimensions and surfaces of each “lastra” and “concio” are extracted and made available for display. Where other information was available for each base element, such as replacements, restorations, and more, these were linked to the single base unit. Other information such as sampling points for mineralogical, petrographic, geochemical and degradation type analyses, instead, have been inserted as a separate information level, appropriately themed and linked via hyperlink to the related reports in *.pdf format.

Any maps of degradation and their typology, detected and returned in raster format, have been georeferenced and vectorized.

Photographs, photo-planes and laser scan surveys, carried out over the years, have been inserted as raster layers in a georeferenced position, so that they have the direct possibility to visualize the historical memory.

As a demonstration of what has been described, Figure 6, represents all the levels that are implemented within the Spatial Information System created for the Battistero di San Giovanni.

Mobile side

After this phase of collecting and organizing the previous information, on the desktop side, the implementation on the mobile side is used to realize an unconventional field mapping application.

Starting from the wireframe divided into single base units, with a survey carried out in situ, the lithology and accessory characteristics are associated with each individual geometry.

The operator has on the mobile app all the single basic elements, identified with an ID and with lithology attributed by photo interpretation. Going near the monument, the operator can verify the correct lithological attribution and the correct geometry or can modify the attribution by simply clicking on the basic element and modify the alphanumeric data (Figure 7). The changes on the geometry instead are reported through a service layer that will be described later.

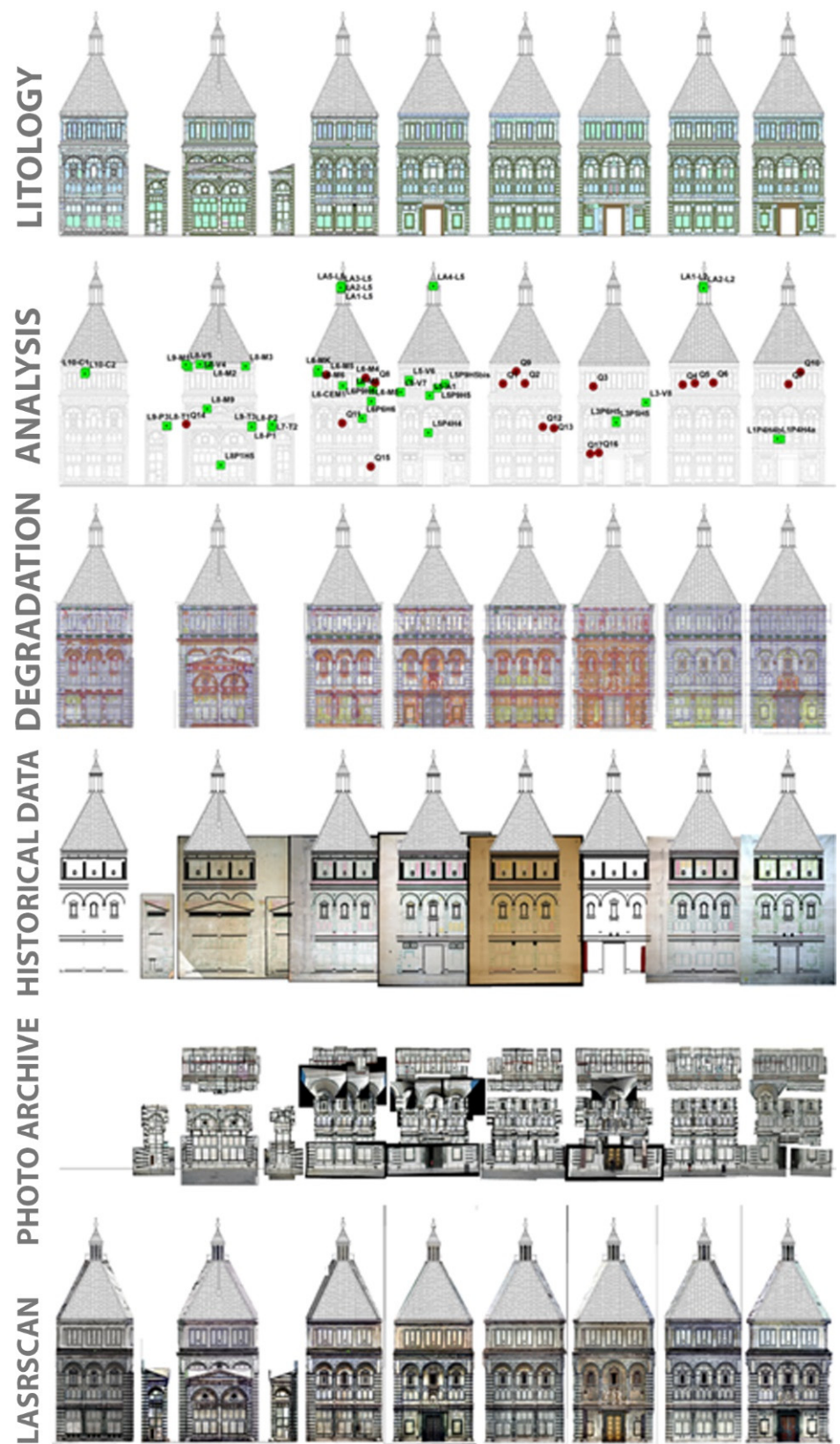


Figure 6. All GIS layer stored in Battistero di San Giovanni project.

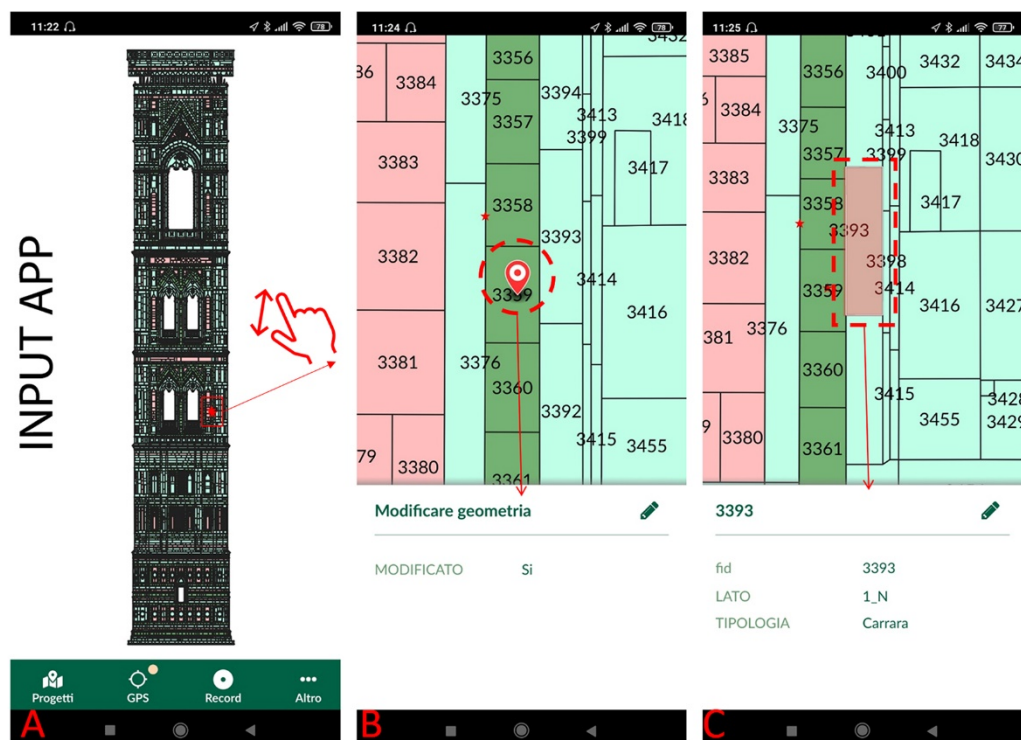


Figure 7. Field mobile survey activity sample. Screenshot (A)—complete view of the themed levels. Screenshot (B)—After zooming in the area of interest, in the example, a point is added on service layer to indicate the necessary geometric modification. Screenshot (C)—by tapping on screen is possible to identify the base element (“lastra” in this case) or edit the lithology attribution.

At this point each base element (“lastra”, “concio” or other layer) is identifiable: its history, any maintenance, cleaning or restoration interventions, problems relating to decay, etc. are recognizable.

To these is added the accompanying documentation, often available only in paper format that has been computerized by scanning and returning in *.pdf format.

The project relating to a complex primary monument is characterized by an articulated and large set of papers and information (e.g., specialized reports, analysis result reports, photo archives) that have been related to the base element (every single “lastra” or “concio”) through the use of the “hyperlink” function. In this way, the display and consultation of the extended drawings connected to the geometric base element was managed.

(b) Implementation of the monitoring and updating tool (mobile).

The main objectives of the mobile survey are verification and control, database maintenance, database consulting.

Typical operations that are carried out on the mobile side are two: going on site and verify the lithological attribution or the geometrical correspondence; the second use is dedicated to maintenance, verification, management of the asset and consult information.

While the second objective can be simply achieved by interrogating the database, the second objective requires further elements. Using the mobile platform as a tool means being able to modify the database itself in a geometric and alphanumeric way.

The modification of the alphanumeric fields is very simple, while for the geometric modification it is necessary to create a new service shapefile, with punctual geometry. This level is equipped with some fields dedicated, for example, to signal the need for geometric modification of the basic element we are viewing (“slab” or “segment”) with binary meaning (e.g., Geometry modification YES/NO, 0–1) and a notes field to indicate, for example, the number of photographs to refer to or some textual note. Starting from a preliminary wireframe and a mapping carried out by lithological recognition from

photogrammetry, photos or archive data, we proceed to the verification by “field mapping” which can take place by using aerial platforms or scaffolding.

The different implementations for the two tested APPs are described below, both QFIELD and INPUT apps were installed and tested on an Android tablet.

QFIELD APP

First step to work with QFIELD app is organized into local folders with a filesystem structure all the materials and information collected in a DB and the different shapefiles created and a QGIS desktop project containing symbology, label and all elements for thematization. Additionally, is necessary a point shapefile which has the function of “SURVEY LAYER”, with fields described in Table 1.

Table 1. Types and names of fields of the insert mask.

Field Name	Field Type and Values
DESCRIPTION	10.920
PHOTO	9.701
PHOTO NUMBER	1.256
NOTE	584

Adding to this folder, a second folder, named DCIM, was created to store the picture taken during survey and a service shapefile, with point geometry as described before.

Through the QGIS desktop interface, all the layers that might need to be modified were made queryable, while the wireframe layer was kept “read only”.

To improve the ease of navigation, “views” have been created in QGIS (called “Map Theme in QFIELD), one for each side (e.g., for the BATTISTERO or for the CAMPANILE) and one for the whole.

INPUT APP

For implementation through input app (inputapp.io), all data has been transferred to an Android device using MERGIN services. In this case, all the data passes through the web using a synchronization service. The project and the data saved locally on QGIS desktop are synchronized through the service made available MERGIN. INPUT app accesses the MERGIN account and proceeds to download the project and data, also in this case there is a point layer which has the function of “SURVEY LAYER”, described in Table 1.

Through the mobile app it is possible to verify and modify the attribution, if an incorrect lithological attribution is found, or a geometry attribution. This last operation is not feasible with the INPUT APP which has limitations in editing. Even using QFIELD, which despite having no limitations in geometric editing, changing geometries is very complex (Figure 7).

2.3. Third Phase

In this third phase of verification and testing, the proposed workflow was applied to three historical monuments: Battistero di San Giovanni, Campanile di Giotto e Duomo di Prato (Figure 8), two of them are parts of the historical centre of Florence, that was entirely declared UNESCO World Heritage Site since 1982.

The Battistero di San Giovanni (Figure 8a), is one of the oldest religious building in the city of Florence, dating back to the XII century. This monument is octagonal in plan, typical of the baptisteries, especially medieval and of byzantine inspiration, and entirely covered with slabs of white and green marble and topped by a dome with eight segments resting on the perimeters walls.

The Campanile di Giotto (Figure 8b) is squared, about 15 m in wide, and 84, 70 m high. It is the most eloquent testimony of Florentine gothic architecture of the XIV century.



Figure 8. General view of the historical monuments on which workflow has been applied: (a) Battistero di San Giovanni; (b) Campanile di Giotto; (c) Duomo di Prato. (Photos a and b by Opera del Duomo Website; photo c from authors).

The Duomo di Prato (Figure 8c) is one of the oldest churches in the city of Prato. Existing at least from the 6th century in was renovated from the 10th to the 15th century with a “two-tone” (bicromia) of the external facades, in Alberese and in Verde Prato. The current structure dates back to a period of reconstruction that began in 12th century and ended in 15th century.

3. Implementation and Results

All three phases were applied to the three monuments indicated, the system thus implemented made it possible to manage a total of 22.996 “lastre” polygons for the Battistero di San Giovanni (Table 2) and 40.660 “lastre” for the Campanile di Giotto (Table 3). In the same way it allows to manage 29.077 “conci” of the Duomo di Prato (Table 4).

Table 2. Types of materials of the Battistero and number of “lastre”.

Types of Materials	Number of “lastre”
Verde Prato	10.920
Carrara Marble	9.701
Imetto	1.256
Lasa Marble	584
Punta Bianca Marble	315
Pentelico	147
Apuana Slate	51
Porfido Rosso Antico	9
Verde Malenco	4
Porfido Verde Antico	2
Calcescisto	2
Cipollino Rubrio dell’Eubea	2
Thassos	1
Breccia Greca Antica	1
Sienitic Granite	1

Table 3. Types of materials of the Campanile di Giotto and number of “lastre”.

Types of Materials	Number of “lastre”
Carrara Marble	27.273
Verde Prato	8.864
Rosso Cintoia	4.523

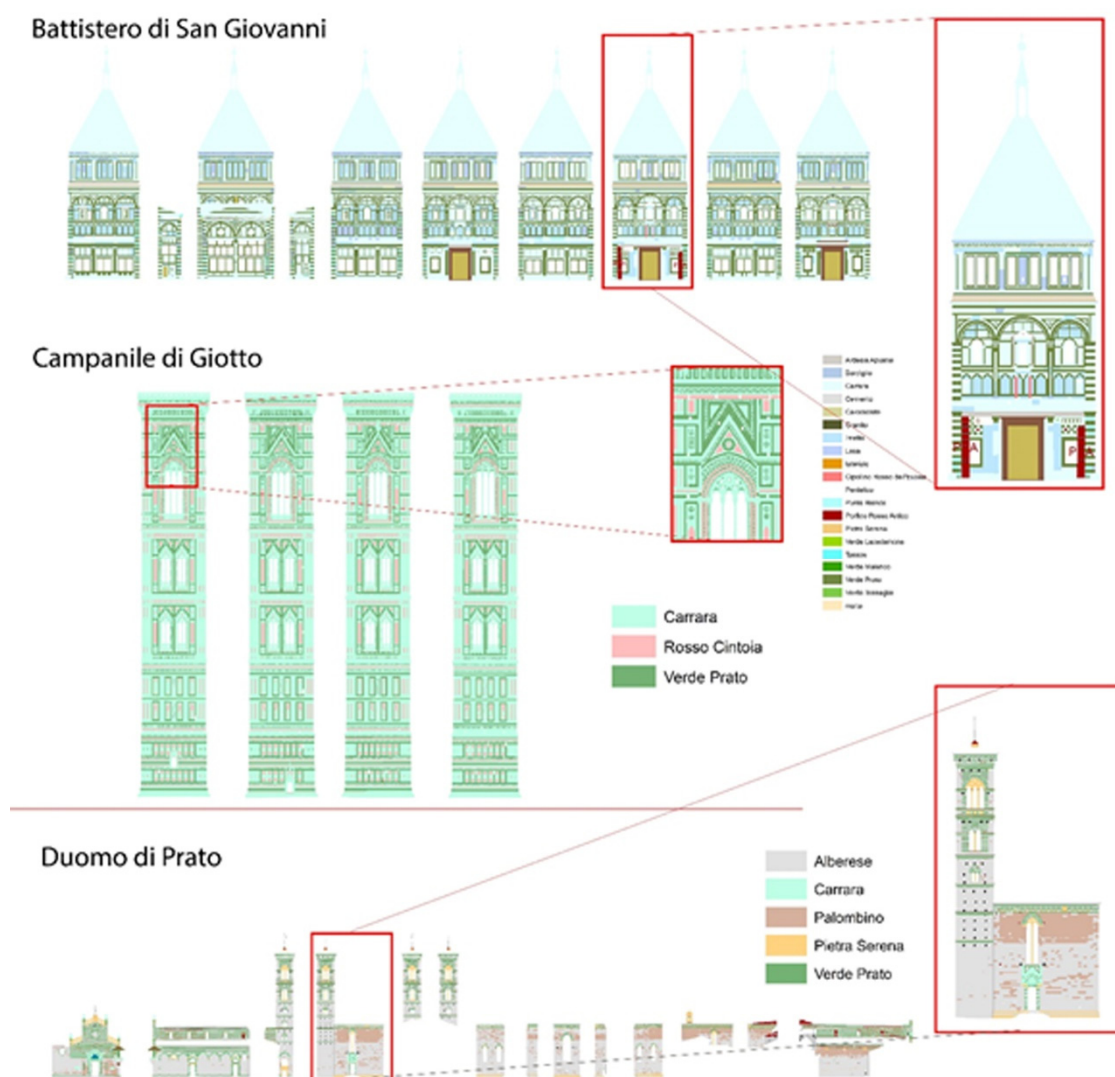
Altogether 15 different lithologies have been identified for the Battistero di San Giovanni, 3 types of material for the Campanile di Giotto and 5 for the Duomo di Prato.

The result is an unconventional lithological map of the coatings of Cultural Heritage, representing the distribution of lithology over the facades.

Table 4. Types of materials of the Duomo di Prato and number of “conci”.

Types of Materials	Number of “conci”
Alberese	16.987
Verde Prato	7.993
Palombino	3.127
Pietra Serena	596
Carrara Marble	374

As shown in Figure 9 the visualization of the coatings of the various monuments generates a “lithological map” with colours representing different lithologies. The visualization is themed by lithology obtained by the integration of what is derived from the archive information integrated with the field surveys.

**Figure 9.** Monument “Lithological map”.

4. Discussion and Conclusions

The proposed workflow allows a single and univocal management of the entire amount of existing data in a relational, dynamic, updatable and immediately available and interrogable way by the operator engaged in the planned periodical inspections of the monuments, optimizing the phases that lead to the identification of priorities for scheduled maintenance and for growth the main dataset.

All the data organized, updated and maintained with the proposed workflow are to be considered as a knowledge organize base, a real structured data base on Cultural Heritage that is a base to develop various application starting form conservation, reaching dissemination and creation of virtual tours or other solutions.

In this proposed workflow we have forced the use of some software that are born for other purposes, in fact demonstrating how these systems are extremely ductile and permit various applications, aimed at making extraordinarily complex processes more efficient and being part of decision support systems.

In relation to the above aspects, it is possible to list below the main advantages that the use of a GIS system brings in the management of a project, such as the one under consideration:

- Unitary management of different data by themes, characteristics and form;
- Management of historical data and information, without having to resort to the examination of paper sources;
- Unique storage of data, thus avoiding errors related to non-unique encodings or data processing carried out by different operators;
- Ease and speed of simultaneous and integrated consultation of a large amount of data, their functional query to needs and their comparison (Figure 3);
- Possibility of customization according to specific graphic and documentary query needs;
- Possibility of data processing;
- Possibility of updating and further implementation in the phases following the design phase;
- Intangibility of data with results deriving from the monitoring phase.

The GIS implementation allows a single and univocal management of the entire amount of existing data in a relational, dynamic, updatable and immediately available and interrogable way by the operator engaged in the planned periodical inspections of the monuments, optimizing the phases that lead to the identification of priorities for scheduled maintenance (Figure 9).

As part of the project, the possibility of proceeding through operational protocols to be followed in the context of the creation, development and modification of data managed in CAD emerged as an element of primary importance, aimed at optimizing and speeding up the implementation process in GIS, but also for a better management of the same data in the CAD environment.

The priority objective of these protocols is to harmonies the working methods currently used for CAD file management with the needs of GIS software, in order to provide main working guidelines to the different operators. At the same time, the definition of design protocols also improves the management of the same data in CAD environment, easily identifiable, modifiable and updatable, in line with the succession of the various design phases, the constantly changing information and the implementation of data.

In particular, on the basis of the experience gained in the context of this project and other previous projects, it became necessary to follow specific operational protocols for the individual points:

- Table data typed in a spread-sheet: use the point or the comma for the decimal digits; define a priori the cell formats and keep them in the different files; do not use merged cells, enter up to 30 characters for each cell.
- CAD data: define and maintain a single digitization verse (clock- or counter-clockwise); pay attention in the closure of polygons (snap), attribute information to all elements; divide the various elements into separate layers; maintain consistency between layers, filling hatch, and legends, avoid blockages, clean up layers.
- File *.pdf: allow opening, printing and file management, without resorting to passwords or permissions in order to use the file in the most appropriate way for the case.
- External data computerization: in order to implement/analyze, as much as possible, proprietary data should be provided in open or adequate digital format (not as images or *.pdf) so that they can be managed with dedicated and appropriate software.

- When a raster data is converted into vector (*.shp) it important to have both the data: the original raster is under the responsibility of the extensor, the correct transposition in *.shp is under the responsibility of the operator.

With a view to possible management in GIS of future projects, it seems important to provide for the elaboration and implementation of operational protocols already from the initial phases of the project; these protocols should be specific to the different topics to be dealt with (e.g., point surveys, linear investigations, ranges, etc.) and developed in agreement and close collaboration with the various stakeholders.

The use of the two mobiles survey platforms (INPUT and QFIELD) showed some limits, essentially due to the difficulty of geometric design that in some cases it was necessary to do.

With both solutions there were drawing difficulties and, in several cases, it was chosen to insert a “simple” point that had the function of highlighting the anomaly and describe the intervention, which would then be corrected with the desktop software.

On the other hand, the situation in case of modification of a value present in a field is quite different, in this case both applications behaved in an excellent way.

There were no difficulties in using the application even if QFIELD app seems to be more fluid in the experience of use.

A possible future application of the workflow could be to bring the virtual visitor closer to the conservation and maintenance of the asset, proposing, in addition to the display of historical and cultural contents, also technical-scientific contents linked to the process’ heritage restoration and conservation. The aim is to encourage participation and information on the protection and conservation of heritage by involving a wide audience using virtual media and content.

The new technologies relating to geomatics, photography and information technology offer significant application for the documentation of Cultural Heritage, as regards the data acquisition and the representation phases, publication and multimedia communication.

The aim is to encourage participation and information on the protection and conservation of heritage by involving a wide audience using virtual media and content, but all this immersive and technological advanced solution needs a solid base represented by a structured, solid and updated dataset that could be realized by the proposed workflow.

Author Contributions: Conceptualization, Niccolò Iandelli; Data curation, Niccolò Iandelli, Tessa Donigaglia and Anna Livia Ciuffreda; Supervision, Massimo Coli; Writing—original draft, Niccolò Iandelli; Writing—review and editing, Niccolò Iandelli and Tessa Donigaglia. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. UNESCO. Convention Concerning the Protection of the World Cultural and Natural Heritage. United Nation Educational, Scientific and Cultural Organization, 1972. Available online: <http://whc.unesco.org/en/conventiontext/> (accessed on 1 January 2021).
2. Box, P. *GIS and Cultural Resource Management. A Manual for Heritage Managers*, 1st ed.; UNESCO Principal Regional Office for Asia and the Pacific: Bangkok, Thailand, 1999.
3. Kutasi, D.; Vidovszky, I. The cost effectiveness of continuous maintenance for monuments and historic buildings. *Period. Polytech. Archit.* **2010**, *41*, 57–61. [[CrossRef](#)]
4. Van Balen, K.; Vandesande, A. *Reflections on Preventive Conservation, Maintenance and Monitoring by the PRECOM³OS UNESCO Chair*, 1st ed.; Acco Uitgeverij: Belegie, Holland, 2013.
5. Xiao, W.; Mills, J.; Guidi, G.; Rodriguez-Gonzálves, P.; Barsanti, S.G.; González-Aguilera, D. Geoinformatics for the conservation and promotion of cultural heritage in support of UN sustainable development goals. *ISPRS J. Photogramm. Remote Sens.* **2018**, *142*, 389–406. [[CrossRef](#)]

6. Agapiou, A.; Lysandrou, V.; Alexakis, D.D.; Themistocleous, K.; Cuca, B.; Argyriou, A.; Sarris, A.; Hadjimitsis, D.G. Cultural heritage management and monitoring using remote sensing data and GIS: The case study of Paphos area, Cyprus. *Comput. Environ. Urban. Syst.* **2015**, *54*, 230–239. [CrossRef]
7. Ortiz, R.; Ortiz, P.; Martín, J.M.; Vázquez, M.A. A new approach to the assessment of flooding and dampness hazards in cultural heritage, applied to the historic centre of Seville (Spain). *Sci. Total Environ.* **2016**, *551*, 546–555. [CrossRef] [PubMed]
8. Vacca, G.; Fiorino, D.R.; Pili, D.A. Spatial Information System (SIS) for the Architectural and Cultural Heritage of Sardinia (Italy). *ISPRS Int. J. Geo Inf.* **2018**, *7*, 49. [CrossRef]
9. Bertocci, S.; Bini, M. *Manuale di Rilievo Architettonico e Urbano*; CittàStudi.: Novara, Italy, 2012.
10. Docci, M.; Maestri, D. *Manuale di Rilevamento Architettonico e Urbano (Grandi opere)*; Laterza: Roma, Italy, 1994.
11. Lezzerini, M.; Antonelli, F.; Colombu, S.; Gadducci, R.; Marradi, A.; Miriello, D.; Parosi, L.; Secchiari, L.; Lazzeri, A. Cultural Heritage Documentation and Conservation: Three-Dimensional (3D) Laser Scanning and Geographical Information System (GIS) Techniques for Thematic Mapping of Facade Stonework of St. Nicholas Church (Pisa, Italy). *Int. J. Archit. Herit.* **2016**, *10*, 9–19. [CrossRef]
12. Pancani, G.; Bigongiari, M. Digital survey for the structural analysis of the Verruca fortress. *Procedia Struct. Integr.* **2020**, *29*, 149–156. [CrossRef]
13. Cavalagli, N.; Giofrè, M.; Grassi, S.; Gusella, V.; Pepi, C.; Volpi, G.M. On the accuracy of UAV photogrammetric survey for the evaluation of historic masonry structural damages. *Procedia Struct. Integr.* **2020**, *29*, 165–174. [CrossRef]
14. Coli, M.; Marino, L. (2008) Principles of the natural stone use and practices from the western side of the Silk-road. In Proceedings of the International Symposium “Conservation of Ancient Sites” 2008 & ISRM-Sponsored Regional Symposium, Beijing, China, 22–24 September 2008; pp. 35–44, ISBN 978-7-03-027158-7.
15. Rodolico, F. *Le Pietre Delle Città d’Italia*; Le Monnier: Firenze, Italy, 1965.
16. Malesani, P.; Pecchioni, E.; Cantisani, E.; Fratini, F. Geolithology and provenance of materials of some historical buildings and monuments in the centre of Florence (Italy). *Episodes* **2003**, *26*, 250–255. [CrossRef] [PubMed]
17. Fratini, F.; Rescic, S. The stone materials of the historical architecture of Tuscany, Italy. *Geol. Soc. (Spec. Publications)* **2013**, *391*, 71–92. [CrossRef]
18. Garzonio, C.A.; Cantisani, E.; Coli, M.; Cuzman, O.; De Luca, D.; Lubritto, C.; Ricci, M.; Vettori, S.; Sibilìa, E. I materiali costruttivi del Battistero. In *Il Battistero di San Giovanni: Conoscenza, Diagnostica, Conservazione, Firenze, Italy, 24–25 November 2014*; Mandragora: Firenze, Italy, 2017.
19. Coli, M.; Donigaglia, T.; Tanganelli, M. Historical construction materials at Firenze (Italy): A selected supply at km 0. In Proceedings of the VI International Conference ReUSO, Messina, Italy, 11–13 October 2018.
20. Sartori, R. *Pietre e Marmi di Firenze*; Alinea: Firenze, Italy, 2002.
21. Salvatici, T.; Calandra, S.; Centauro, I.; Pecchioni, E.; Intrieri, E.; Garzonio, C.A. Monitoring and evaluation of sandstone decay adopting Non-Destructive techniques: on-site applications on buildings stones. *Heritage* **2020**, *3*, 1287–1301. [CrossRef]
22. Coli, M.; Donigaglia, T.; Papeschi, P.; Boscagli, F.; Agostini, B.; Caselli, G. GPS Applications for NDT Investigations on the Cultural Heritage Monumental Buildings of Florence (Italy). *J. Civ. Eng. Arch.* **2019**, *13*, 415–426. [CrossRef]
23. Vasconcelos, G.; Lourenço, P.B.; Alves, C.A.S.; Pamplona, J. Ultrasonic evaluation of the physical and mechanical properties of granites. *Ultrasonics* **2008**, *48*, 453–466. [CrossRef] [PubMed]
24. Akoglu, K.G.; Kotoula, E.; Simon, S. Combined use of ultrasonic pulse velocity (UPV) testing and digital technologies: A model for long-term condition monitoring memorials in historic Grove Street Cemetery, New Haven. *J. Cult. Herit.* **2019**, *41*, 84–95. [CrossRef]
25. Burrough, P.A.; McDonnell, R. *Principles of Geographical Information Systems*; Oxford University Press: Oxford, UK, 1998.
26. QGIS. Available online: <https://qgis.org/it/site/> (accessed on 12 January 2021).
27. Ostadabbas, H.; Weippert, H.; Behr, F.J. Using the synergy of QFIELD for collecting data on-site and QGIS for interactive map creation by ALKIS@data extraction and implementation in PostgreSQL for urban planning process. *Int. Arch. Photogramm. Remote Sens. Spatial. Inf. Sci.* **2020**, *XLIII-B4-2020*, 679–683. [CrossRef]

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