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DESIGNING THE METRIC SURVEY FOR BUILT HERITAGE DOCUMENTATION USING 360° IMAGES AND AN ONLINE CLOUD-BASED PLATFORM

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ABSTRACT:

The documentation process of Built Heritage could be really challenging, and managing the different phases of this process is not always straightforward. The metric survey design is still one of the most complex and delicate tasks in the overall process: it drives the activities of data acquisition, processing, validation, interpretation, and final product delivery. It encompasses several aspects: stakeholders involvement, choice of instruments and techniques, available resources (not only economical but also in terms of human resources) timelines, etc. Moreover, a wrong or inaccurate metric survey design can lead to significant mistakes during the data acquisition phase that can result in the collection of redundant data or, worst-case scenario, a lack of data. After a brief state-of-the-art in the European and Italian framework, the research presented in this work will focus on the different aspects of the documentation process and, more specifically, on new digital tools that can assist this step of the Built Heritage documentation. More specifically, the contribution will focus on 360° cameras and the related cloud-based platforms for using and sharing these types of data. This market sector has been rapidly growing in the last years, and we faced a lowering of the purchase costs for these systems together with a wider availability of different sensors. Finally, the resolution has reached exciting levels with sensors that can record 360° data up to 6K/8K.

1. INTRODUCTION

In the overall documentation process of Built Heritage, one of the most challenging and crucial activities is still related to the design of the metric survey process. The survey design is the essential phase that will drive all the activities of data acquisition, processing, validation, interpretation, and final product delivery. It encompasses several aspects: stakeholders involvement, recovering of already existing data, final deliverables, choice of instruments and techniques, available resources (not only economical but also in terms of human resources), timelines etc. Moreover, a wrong or inaccurate survey design can lead to significant mistakes during the data acquisition phase that can result in the collection of redundant data or, worst-case scenario, a lack of data. The survey project needs to be thoroughly planned and designed before the data acquisition phase, and it requires the involvement of all the operators revolving around the process of Built Heritage documentation and its subsequent use. This contribution aims to evaluate and assess the support that new and consolidated digital instruments can give to this preliminary phase of Built Heritage documentation, as well as the overall documentation process. In particular, the focus will be on 360° images and videos and cloud-based platforms that exploit the immersive content of these digital products.

1.1 The European Scenario of Built Heritage Documentation

In the scientific literature, it is possible to retrieve several texts addressing the Built and Cultural Heritage documentation from different perspectives (e.g., Letellier, 2007; Remondino & Stylianidis, 2016; Waldhäusl, P., Ogleby, 1994).

Over the years, researchers focused their efforts on both technical and methodological issues. The technical issues are multiple, and this topic can be developed under several points of view: which is/are the best instruments or techniques to use depending on the surveyed heritage assets, how to cut cost and time; how to manage the different information and level of details; how to connect the metric information with other kinds of data; how to generate models supporting the goals for documenting, etc.

On the other hand, from the methodological point of view, authors have been discussing more theoretical matters such as: why the documentation is needed, who will use the data and how, what needs to be represented, what metrical accuracy needs to be guaranteed for the different derived products, etc.

Despite the interest in this topic, it must be reported that few attempts have been made to summarize and collect all these issues in a single and coherent text due to the complexities that this operation requires.

Suppose we try to reduce the field to the European scenario. In that case, the most known works in this sense are the ones edited by Historic England that established a reference text for the documentation of English Heritage with the Metric Survey Specifications for Cultural Heritage (Andrews et al., 2009).

Historic England is a public body of the British Government in charge of protecting (in its broader sense, from the identification of the heritage asset to its promotion and management) the English Heritage. Among the different tasks of this entity, a lot of efforts have been devoted over the years to listing and documenting this heritage. These efforts have been collected and reflected in a series of texts acting as technical guidance for the operators working in the heritage field.

As previously reported, the most known text is the Metric Survey Specifications for Cultural Heritage (MSSCH) which reached its

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third edition in 2015 and should be soon updated to the fourth edition. The text is highly detailed, starting from the definition of general terms and requirements of a metric survey in the heritage field and with specific sections dedicated to single survey techniques (e.g., topographic survey, image-based survey, laser scanning, etc.).
Furthermore, over the years, the MSSCH have been flanked by several other handbooks committed to specific techniques: (Historic England, 2017a, 2017b, 2018b, 2018a).
However, especially if we look at the Italian context, procedural handbooks are still missing. These texts would be helpful to set the terms of reference for the process of Built Heritage documentation. They could aid the national entities in charge of managing and safeguarding this heritage. The urgent need for these reference texts is clear at the national and international levels and is particularly critical in the Italian scenario.
In this sense, a recent attempt in this direction is foreseen in the new *Piano Nazionale per la Digitalizzazione* (National Plan for the Digitalization - PND) that is moving toward this direction intending to enhance the digitalization (Ministero Italiano della Cultura & Istituto centrale per la digitalizzazione del patrimonio culturale - DIGITAL LIBRARY, 2022). The *Istituto centrale per la digitalizzazione del patrimonio culturale* - DIGITAL LIBRARY is in charge of the drafting of the plan; the plan is composed of a series of documents defining the strategic vision of the Italian Ministry of Culture and represents a good starting point for the setup of procedural handbooks targeted to the documentation process of different CH assets.
After the first draft was completed, the plan was published for an open consultation to collect feedback from the different stakeholders involved in the process. The plan contains the strategic vision of the Italian Ministry of Culture for the five years term between 2022 and 2026, and it is aimed at all the entities in charge of heritage management, conservation, safeguarding, and promotion. The plan is divided into three main sections: i) Vision, ii) Strategy, and iii) Guidelines. For the purposes of this contribution, the most interesting section is the one dedicated to guidelines definition. This is the most technical part of the PND where the different approaches for data acquisition and processing are reported together with the management of the collected data. However, due to its border objectives and its complexity, the actual version of the PND is not too focused on the individual-specific approaches and the design of the survey project. Thus further research and practical handbooks are still needed (this is something foreseen for the future versions of the PND). Therefore, this contribution aims to add a small piece to this broader puzzle, contributing to the enhancement of the overall documentation process of the Built Heritage.

1.2 The documentation process for Built Heritage

The definition of the documentation process for Built Heritage it's not an easy task; multiple factors need to be considered, and several issues need to be addressed. In general terms, the documentation process can be summarized in three main phases (this simplified pipeline is shown in Figure 1):

1. Preliminary research
2. Definition of the survey project
3. Data acquisition and processing

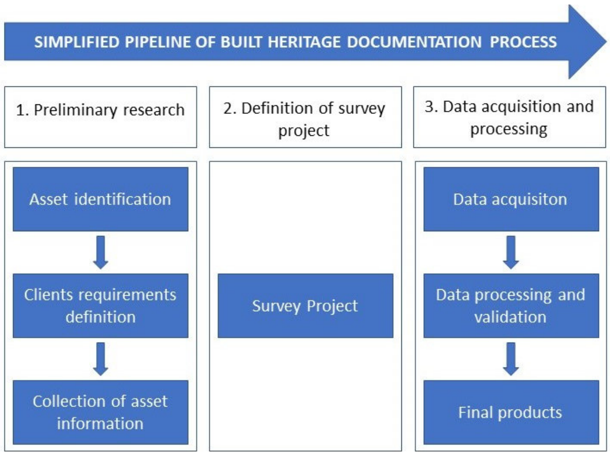


Figure 1. Simplified scheme of the Built Heritage documentation process.

The first phase encompasses all the tasks devoted to collecting information about the asset that needs to be surveyed and the requirements of the different stakeholders involved in the process. This phase also includes the research of archival data and the availability of previous surveys (that need to be validated). Identifying the stakeholders' needs is another crucial step that influences the definition of the survey projects, the decision on which techniques to use, and the delivery of the final products.
The second main phase of the process is the design of the survey project, the core of the overall documentation pipeline. The survey project collects all the input from the preliminary research and defines and influences the third phase of data acquisition and processing. For the design of the survey project, it is mandatory to have access to all the possible information about the asset to be surveyed, and it is generally advised to complete also an onsite visit when possible. In this step, all the activities to be conducted on the field will be decided: the creation of a first and second-order topographic network, the selection of the techniques to be used (and for each technique, the definition of the acquisition strategy as well as the integration between different techniques), the overall planning of fieldwork (time, resources and operators involved).
Finally, the last main step encompasses the data acquisition, processing, validation, and final product delivery to the stakeholders.

2. NEW DIGITAL TOOL ASSISTING THE DESIGN OF THE SURVEY PROJECT

To integrate the recommendation contained in the PND in the overall documentation process of Built Heritage, we will attempt to deepen some strategies to enhance the phase of survey project design. Among the different digital tools that can assist in the design of the survey project, we decide to focus on 360° cameras and the cloud-based solution for managing and using this kind of data thanks to the speed and ease use and the wealth of collected information. The diffusion of these devices in recent years has been rapidly growing, thanks to the lowering of the prices and the increment of the models available on the market; moreover, their resolution has reached exciting levels with sensors that can record 360° data up to 6K/8K. The interest in these data in the geomatics community has also been confirmed by the different tests and experiments concerning the use of 360° contents adopting a photogrammetric approach. The first experiments have been already conducted in the past (Fangi, 2007, 2009; Fangi & Nardinocchi, 2013), while a new interest can also be

traced in recent works (Barazzetti et al., 2017, 2018; Fangi et al., 2018; Teppati Losè et al., 2021).
On the other hand, also the heritage field is not new to this kind of data: indeed, 360° images and videos have been used in the form of virtual tours in the last decade for valorization, tourism and promotion purposes.

2.1 360° cameras and cloud-based platform

As happened for the heritage domain, one of the first use of 360° data was related to creating virtual tours. Recently, these solutions faced a rapid evolution in the market, and the idea of the virtual tour has regained popularity with new developments.
Looking at the evolution of the market, it is possible to find different solutions that transformed the idea of virtual tours. At first instance, three different solutions were identified: Cupix (https://www.cupix.com/), Matterport (https://matterport.com/), and Holobuilder (https://www.holobuilder.com/). We selected these platforms for various reasons but mainly because they permit the integration of the virtual tour with other data (such as 3D models), can manage the multitemporal acquisition, and can be used to add tags and/or assign tasks to specific operators supporting a collaboration between different levels of users during construction processes too. These solutions are mainly developed for the AEC (Architecture, Engineering, and Construction) sector and the real estate market; however, they could also be used to aid the documentation process of Built Heritage with a promising degree of success. In this first research, we decided to focus on the Holobuilder platform that was recently acquired by FARO Technologies Inc.
To test the possibility of using this platform in a real case scenario, it was decided to simulate all the different phases of the documentation process on part of a complex Built Heritage asset that was surveyed in the recent past: the Castello del Valentino (Figure 2) in Turin (Italy).

Figure 2. The Castello del Valentino.

The Castello del Valentino was built in the XVI century and soon became the residence of the royal Savoy family. It has undergone several transformations over the centuries until it became the Royal School of Application for Engineers in the sixties of the XIX century. From the late forties of the XX century, the castle became the property of the Politecnico di Torino and now hosts the Architecture & Design Departments. In 1997 it became part of the UNESCO World Heritage List. Due to its complexity and articulation, for this first test only a portion of the castle was used as a case study; more specifically, the first floor of the main building: the Noble Residential Floor. This part of the castle was the representative floor of the court; it is decorated with stucco and frescoes and composed of 13 different rooms.
The 360° camera tested in our case and coupled with the Holobuilder app was a Ricoh Theta Z1 (Figure 3); the main technical specifications are reported in Table 1.

Figure 3. The camera used for the test with Holobuilder: Ricoh Theta Z1 (source: https://theta360.com/it/about/theta/z1.html)

Ricoh Theta Z1	
Dimensions	48 mm/132.5 mm/29.7 mm
Weight	ca. 182 g
Image resolution	6720x3360 pixel
Max video resolution	4K - 3840 x 1920 (29.97fps)
Sensor (x2)	1-inch CMOS sensor
Effective pixels	23 MP

Table 1 Ricoh Theta Z1 technical specifications

The integration of this platform in the documentation process can be exploited in all three phases reported in Figure 1.
In the first phase (the preliminary research on the asset), it is possible to acquire 360° data during the in situ visit of the asset to create rapidly a 360° images database. The 360° panoramic images are related to the floorplans of the assets (it could also be a sketch or some pre-existing documentation) and are acquired directly with the dedicated smartphone/tablet application (Figure 4).

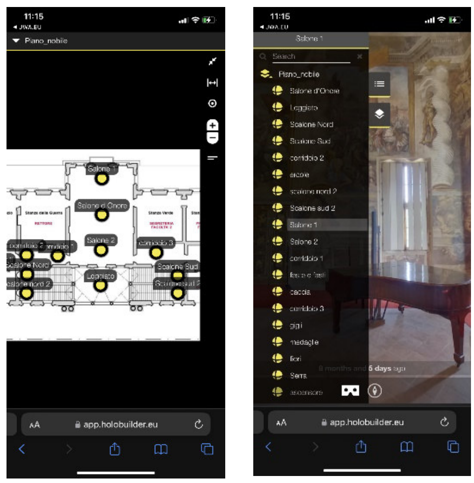


Figure 4 The User Interface of Holobuilder App.

During the acquisition, it is also possible to acquire 2D images with the user's mobile device and associate them with their location on the 360° image. This feature can be helpful in case of complex heritage to add a preliminary database of 2D images of peculiar details observed during the in situ visit. In the same way, it is also possible to add alphanumeric tags on the 360° images to take note of other details that could be useful in the subsequent phases (e.g., the position of illumination sources that can affect a photogrammetric survey, the presence of some obstruction that can have an impact on the laser scanning acquisition, etc.).
Directly from the site, after the acquisition phase of spherical images, the project is automatically processed and uploaded to

the cloud. From now on, it can also be accessed via a web browser, and it is possible to set up access for different users with different levels of privilege on data editing and visualization. It is thus possible to share the project with all the involved stakeholders, and different operators can contribute to the enrichment of the platform depending on their expertise. It would be possible to add other information, such as the results of the archival research that might have highlighted some specific details on the asset. It has to be highlighted the importance of this solution to provide a set of information and a series of data to everyone who couldn’t visit the asset in person.

The data are available on the online platform and can also be employed to collect specific needs of the clients of the survey, e.g., the major areas of interest where a higher level of details will be needed or particular points of attention for the operators that will design and execute the survey.

It is also interesting that 360° data acquisition is easy and guided by the mobile app, meaning that non-expert users or clients can perform it. This feature is convenient for assets with limited access for time, location, or environmental constraints. Moreover, the acquired images can be measurable if the 360° camera is mounted on a tripod of known or measured height. The accuracy of the measurements obtained on 360° images following this approach is in the order of some centimeters depending on different factors, but is sufficient for the survey design phase, especially for the sizing of the areas that need to be surveyed and an estimation of the time required to complete the fieldwork. Finally, acquisitions can be reproduced over time in the same position; thus, enriching the image database from a multi-temporal perspective is possible. This feature is particularly valuable in case of change in the site between the different visits or in a multitemporal monitoring perspective.

An example of the data acquired for the Castello del Valentino with Holobuilder is reported in Figure 5.

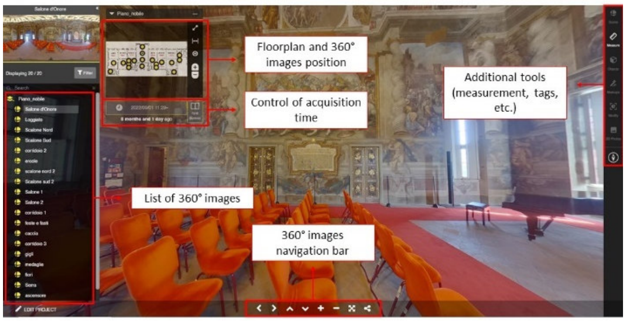


Figure 5. Holobuilder viewer browser interface

In our test case, 20 images were acquired with the 360° camera and the Holobuilder app: the acquisition time was of 20 minutes. The second phase, (the design of the survey project), is where the use of this, or similar solutions, can be really fruitful.

It is possible to define the survey project using all the information retrieved in Phase 1 and the 360° images. As for the first phase, it is possible to annotate the 360° images in the platform in various ways with notes, photos, sketches, and external links and also assign specific tasks to single operators.

Using the data and tools available in the cloud platform, the surveyor can plan all the subsequent survey operations in detail. The first step is the definition of the first and second-order control network. The correspondence between the floorplan and the 360° images makes it possible to decide the position of the network vertices and verify the intervisibility between the different vertices (Figure 6).

This last step is limited if working only on a 2D floorplan, and the in situ visit might not be sufficient to carefully think about and design the network. Moreover, it could be necessary to extend or modify the network over time due to a change in the stakeholders’ requirements or the environmental condition of the asset, and planning another in situ visit might not always be possible.

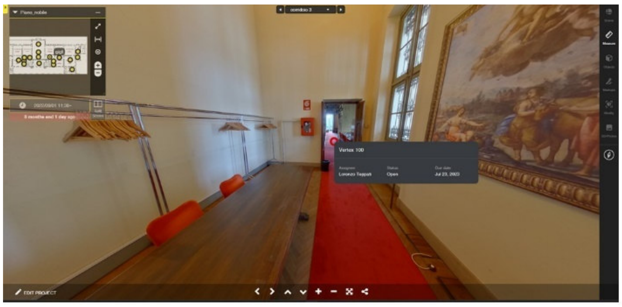
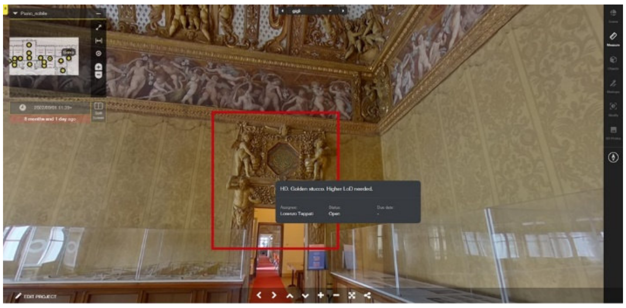


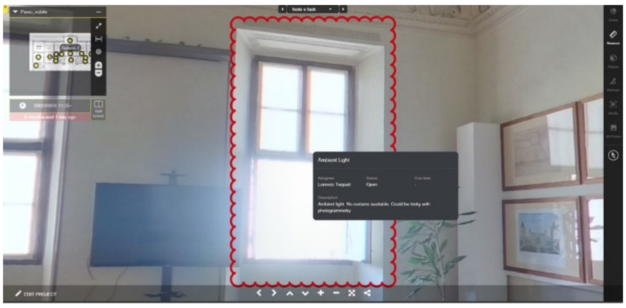
Figure 6. Example of topographic vertex planning. In this case, the task of materializing and measuring a specific vertex can be assigned to a specific operator with a due date.

The second crucial step of the survey design phase is the definition of the techniques to use and how to integrate them. Even in this case, this series of decisions is influenced by the results of the information gathered in the previous step of the documentation process. Among the several factors that should be considered, its worth reminding: the type and accuracy of the final products defined with the stakeholders, the level of detail and the type of information that they need to embed, the environmental conditions, and the available resources (time, people, cost).

The cloud-based platform can support also in this part of the survey project design. On the 360° images, it is possible to note areas where a higher level of details or additional information is needed (Figure 7-a) or peculiar environmental information that could influence the acquisition phase (Figure 7-b).



(a)

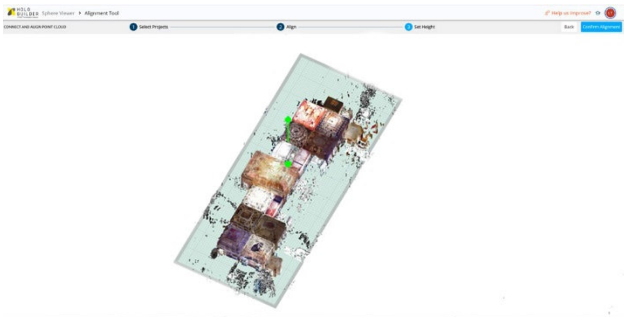


(b)

Figure 7. Example of different use of the markup tools. Reporting of areas that need a higher level of detail (a) and warning on possible lighting issues due to environmental conditions (b)

The possibility of giving access to the cloud platform to several operators is also essential in the fieldwork planning phase and in estimating the cost, time, and resources to deploy during the data acquisition phase.
The use of markups assigned to the different operators can be used to divide the activities to be completed. Thanks to a careful subdivision of tasks, it is thus possible to assign the work based on the different operators' skills and expertise, allowing a smooth field activity and optimizing the overall process.
Moreover, it is possible to set a due date for each markup, with the possibility of creating an enhanced schedule of the activities, and it is possible for the operators to whom the task has been assigned to change its status (e.g., "in progress", "completed", etc). On the other hand, for the survey coordinator, it is possible to track the progress of the work.
Finally, the availability of the 360° database, and the possibility of obtaining rough measurements from it, are helpful for the definition of the tender with the client. This operation allows to estimate the cost and time needed to complete the acquisition phase and is critical for the setup of the contract with the client.
The advantages of using the 360° cloud-based platform are multiple also in the third phase of the documentation process (data acquisition and processing) to assist the data acquisition, processing, and interpretation.
In the acquisition phase, the 360° data can be used as a guideline for the fieldwork activities from the involved operators with two main modalities: i) using the smartphone/tablet app or the browser application, ii) exporting ad hoc pdf report from the platform and using them in the field.
The first approach is by far the more convenient, allowing real-time interaction with the 360° database. The operators have in their hands all the information gathered in the first two phases of the documentation process. They can follow the directions created in the design of the survey project more interactively. With a mindful implementation of the tasks and markups inside the platform, each operator can have its role described and the activities to be completed sorted with a clear order of priority. Furthermore, using the mobile app, it would be possible to acquire other 360° images to document the survey activities as well as add additional information in the form of 2D images or notes. The latter operation has a low incidence in terms of time and cost during the fieldwork activities but represents essential information/documentation of the documentation process itself.
After the acquisition phase, the data contained in the platform are used as support documentation for the processing phase, due to the information and data they hold. For example, in the platform is possible to note the position of Terrestrial Laser Scans (TLS) acquisitions, some information on the photogrammetric acquisition scheme, data on the topographic measures made in the field, etc.
For example, if coded targets are used and measured with traditional terrestrial techniques, it is possible to mark their position and details on the spherical images acquired during the fieldwork. This solution allows to have an interactive and complete overview of the targets. It may replace using sketches or other supports to note all these details during the field activities.
An important step further in the development of the platform has been made recently with the possibility of integrating 3D data in the form of point clouds. This solution was made possible thanks to the integration with the FARO Sphere ecosystem (https://www.faro.com/en/Products/FARO-Sphere) the company's cloud-based platform.
This solution is mainly conceived to work with TLS data; however, it can be successfully used with point clouds derived from any other sources. At the time of writing, the software is conceived to work inside the FARO platform suite, but it would likely be implemented in the future to work with different data sources.
After uploading the point cloud to the cloud, it can be aligned with the Holobuilder floor plan. This registration process is achieved using two homologous points at the floor level and setting up the elevation component of the point cloud concerning the floor level of the plan (Figure 8).
It is clear that this strategy for the alignment between the 360° database and the floorplan has some limitations (e.g., the floorplan should be scaled and with a sufficient level of detail), but it represents a good starting point for example in the case of an easy evaluation of the building consistency and correspondence with archived plans and documents collected.

(a)



(b)

Figure 8. Point cloud alignment inside Holobuilder. Two points picking on the plan (a) and elevation definition between the point cloud and floor level (b)

After the alignment phase, the point cloud is linked with the 360° database and can be navigated and measured. At the moment, those are the only operation available, but other tools are under development and should be released in the future. In any case, this solution represents a possibility to share the 3D data in the form of a point cloud among all the stakeholders using bubble view derived from the laser scanning phase too. The delivery of these kinds of data is usually tricky due to the need for open-source or commercial software to open the file, the weight in terms of disk space, and the inexperience of the stakeholders in managing this type of data.
Having the point cloud uploaded and synched with the 360° database (Figure 9) represents an excellent solution to overcome these issues and made the 3D data available to non-expert users through a simple web-based solution.

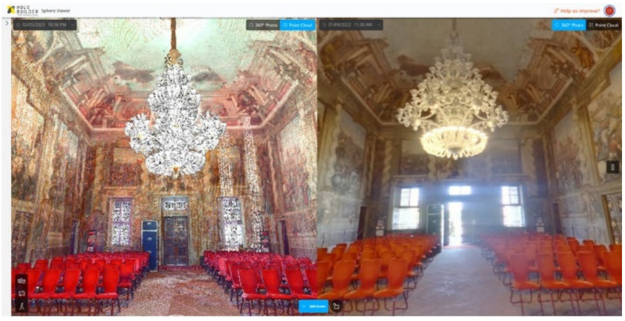


Figure 9. Side-by-side view between point cloud (left) and 360° image (right)

Concerning the delivery of the final products of the survey, it is not unusual in the field of Built Heritage documentation the demand for traditional 2D drawings with a high level of detail. This phase is one of the most time-consuming in the overall documentation process and probably also one of the most challenging. The generation of 2D drawings is always an interpretative process and a high amount of experience is requested by the operator in charge of this operation.
The 360° image database and the registered point cloud can also help in this phase. In case of doubt or need for further information aside from the one that can be derived from the other survey products, the drawers can use the platform to retrieve this information (Figure 10).

Figure 10. Example of integration between the floorplan (containing the position of the acquired 360° images) and the point cloud.

A final remark needs to be added on the further developments that this and other platforms are chasing: the integration with Computer Aided Drawing (CAD) and Building Information Modelling (BIM) format.
Integrating these additional products represents a step forward in connecting reality with its digital representation. They will be crucial in the future for the documentation process of Built Heritage and its maintenance and management. While the advantages of these developments are pretty straightforward in the AEC sector, especially for the monitoring of building sites, their use in the heritage field needs to be further investigated.

3. DISCUSSION AND CONCLUSIONS

After the test performed with the 360° cameras and the cloud-based platform to assist the documentation process of Built Heritage, it is possible to draw some first conclusions. We considered having identified and highlighted multiple benefits in implementing this solution throughout the three phases of the process. These benefits encompass several aspects: from a general optimization of the documentation process in terms of time reduction, and better optimization of the available resources to better management of the overall survey activities.

The learning curve for using this solution has been considered and evaluated as it has been verified that the relationship between time and quantity of information learned from different operators is quite good. That statement can be considered accurate for different types of users with varying levels of computerization.
This matter can be divided into two subtopics depending on the role of the involved operators: the one in charge of the 360° database creation and the one that will just use it. It is interesting to notice that we didn't record critical issues on both sides and thus we can say that this kind of solution is easy to use for all the involved stakeholders.
For their nature, the 360° data are versatile and flexible; thus, it is possible to use the same images acquired to support the documentation process for other purposes. A clear example is the possibility of creating a "classical" virtual tour for touristic and promotional purposes and sharing it with local communities or groups of citizens. As for the standard virtual tour, it is possible to control the type of information to share and embed in the platform to create ad hoc solutions depending on the heritage asset object of the documentation and its environment.
We still haven't tested the feature that allows integrating BIM and CAD models on the platform, and this will be part of future research. Potentially, this integration will further extend the flexibility of these kinds of solutions in the whole life of the Built Heritage asset, supporting its ordinary and extraordinary maintenance and moving one step forward in the world of the so-called digital twins.
There are some drawbacks and issues that we had to face during the overall testing of the platform.
The first theme is connected with the effort we had to complete to adapt the tested solution to the needs of a Built Heritage asset. As reported in the first part of the article, these solutions have been developed to assist the AEC sector. Thus they are conceived to perform optimally, mainly in the scenario of under-construction buildings. We are all well aware that the needs and requirements for the Built Heritage domain are quite different; thus, there wasn't any prebuilt solution for this domain. Luckily, the software and its overall pipeline proved to be flexible enough to adapt to the needs of Built Heritage documentation. We were able to find some workarounds to satisfy our requirements.
To summarize, some features are still missing inside the platform and could be of great help for the documentation process of Built Heritage.
First of all, the possibility of working and integrating georeferenced data is crucial in this domain and a feature that is currently supported only for a few camera models. At the moment, these values could be only upgraded as textual attributes of the data.
Additional commands for the interaction with the point cloud could be beneficial: segmentation, filtering, management of a single part of the point cloud, etc.
Another attractive option would be connected with the possibility of having additional information on the accuracy of the point cloud used. This information should be provided by the user based on the survey report for each available dataset, but having this information inside the platform could be convenient.
Another integration that could be developed is the one with a Geographical Information System (GIS), which can be used to manage the position of the 360° images; that could be georeferenced in case of outdoor acquisition thanks to the GNSS (Global Navigation Satellite Systems) receiver equipped in the 360° camera. This integration will open the platform to a series of other integration with all the tools available in GIS for spatial data analyses.
The last possible integration is with other added-value metric products such as orthoimages or highly detailed 3D models (e.g.,

in the form of 3D pdf) that will add additional informative instruments to the platform.
Finally, based on our tests and experience, it is possible to say that the cost-benefit equation for using this platform in the Built Heritage documentation domain is more off-balanced on the side of benefits.
As a preliminary experience, we were able to identify several strengths on some weaknesses as well as different features that could highly implement the benefit of using this solution if implemented in the future.

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