THE CATHEDRAL OF SAN MASSIMO IN FORCONA (AQ): ARCHAEOLOGICAL ANALYSIS AND INTEGRATED DIGITAL EXPERIENCES FOR VR EXPLORATION AND SITE ENHANCEMENT

A. Arrighetti[1,4] , B. Fanini[2] , D. Ferdani[3] , A. Forgione[4] , A. Lumini[5] , R. Manganelli Del Fà[6] , S. Pescarin[7] , M. Repole [8]

[1] École normale supérieure - Université PSL, France - andrea.arrighetti@ens.psl.eu
[2] Institute of Heritage Science, CNR of Rome, Italy - bruno.fanini@cnr.it
[3] Institute of Heritage Science, CNR of Rome, Italy - daniele.ferdani@cnr.it
[4] Department of Human Science, University of L'Aquila, Italy - alfonso.forgione@univaq.it
[5] Department of Architecture, University of Florence, Italy - andrea.lumini@unifi.it
[6] Institute of Heritage Science, CNR of Florence, Italy - rachele.manganellidelfa@cnr.it
[7] Institute of Heritage Science, CNR of Florence, Italy - sofia.pescarin@cnr.it
[8] Epigraphy & Research Field School, ARCE, USA - marco.repole@gmail.com

Commission II

KEY WORDS: Archaeology of architecture, 3D survey, 3D modelling, digital technologies, interactive layers, web3d.

ABSTRACT:
The contribution aims to present the results obtained from the archaeological analysis of the architecture of the Cathedral of San Massimo in Forcona (AQ), which took place in 2021, focusing on the digital systems used for the documentation and valorization of the monument. The work is part of a broader research project developed by the University of L'Aquila and focused on the archaeological study of medieval architecture as a function of the creation of a database on a chronological-typological basis of the masonry construction techniques of the city and its territory. The first structure to be analyzed was the Cathedral of San Massimo in Forcona, which, although it is located at a significant distance from the city center, represented a power pole of fundamental importance for the political-economic administration of the territory, at least until the construction of the city of L'Aquila. The documentation carried out through integrated TLS/SfM digital surveys and archaeological analysis allowed first to establish a chronological sequence of the construction phases of the church, but also to hypothesize through 3D reconstructions the historical evolution of the entire architectural complex. These reconstructions then became the digital support for the creation of a series of immersive VR systems aimed at providing experiences of interactive storytelling and dissemination of research outcomes.

1. INTRODUCTION

The evolution of digital reconstruction methodologies and software for interactive use represents a turning point for the dissemination and archiving of monuments belonging to our cultural heritage (Brusaporci et al., 2021). Especially in the case of architectural emergencies located in particularly inaccessible places or in the presence of severe limitations such as during the recent pandemic period, or in the case of sites that are impossible to reach for people with physical limitations, this kind of methodologies makes it possible to broaden the plethora of possible users or to stimulate the influx in other cases by intriguing the spectator.

The Cathedral of San Massimo in Forcona, due to its location, morphology and historical significance, represents a perfect context in which to test the potential of an interdisciplinary method of analysis and documentation. The latter is based on the integration of different digital survey, analysis and virtual reconstruction techniques, ranging from the three-dimensional restitution of the current state of the architectural complex to a hypothesized reconstruction of its original model, integrating all the information obtained from the analyses conducted on the artefact. In particular, the work was developed pursuing different aims and operative methodologies. The first based on reconstructive models of an informative nature and an immersive experience of the church in its current state and at the end of the Middle Ages. The second, also based on 3D models but with a more specialized nature, in which an attempt was made to highlight the transformations of the building that emerged from the archaeological analyses. These reconstructions have also been enriched with a wide range of multimedia and textual information that reinforces the potential for dissemination and stimulates a comprehensive fruition of the architectures of the religious complex.

2. HISTORY AND TOPOGRAPHY OF THE SITE

The primitive episcopal location of the territory under examination (fig. 1) is to be found in the nearby Roman *praefectura* of Aveia (the present-day town of Fossa in the province of L'Aquila), which, after its destruction at the end of the fifth century, merged into the Forcona one (Miliario, 1995; Giuntella, 2003). To find the first mention of a bishop from Forcona in the documentation at our disposal, it is necessary to go back to 680, when "*Florus exiguus Episcopus Furconensis Ecclesiae*" subscribed to Pope Agathon's Roman Council (Pani Ermini, 1972). The presence of a bishop *Albinus* is ascribed to the 7th-8th century, whose mention is reported in the well-known sarcophagus dedicated to him found in the bell tower of the building and later transferred to L'Aquila Cathedral (Alinari, 1935; Redi et al., 2012; Pani Ermini, 1972). Between the late fifth and seventh centuries, therefore, the bishop's presence in the territory was extremely lively, as was the town of Forcona, which fully attests to its prosperity, as stated by Paolo Diacono himself, who in 576 described it as the only important town of the western Vestines. The *series episcoporum*, after the information engraved on the sarcophagus of Bishop Albinus, only resumed in 853, when *Ioannes* participated as bishop of Forcona in the Roman Synod of Pope Leo IV, while on 24 March 867 he was called by the edict of Emperor Ludwig II to participate, as feudal lord of the Duke of Spoleto, in the military expedition towards

https://doi.org/10.5194/isprs-archives-XLVIII-2-W4-2024-17-2024

Benevento (Muratori, 1742). The figure of the bishop continued to grow until the middle of the 11th century, when he was of extreme importance in the Italian political scene: in 1059 he belonged to the papal court (Alinari, 1935), while the following year he is attested in a meeting in the castle of Aquili between Pope Nicholas II and Duke Robert. It is precisely at this juncture that the erection of the Cathedral of San Massimo (fig. 2) is probably to be ascribed, precisely at a time of enormous wealth and disposition on the part of the bishop of Forcona, perhaps Bishop Walterio, a *protégé* of Emperor Otto I and Prince Pandolfo Capodiferro, or Bishop Ranieri, elected by Pope Nicholas II himself. In any case, the bishop from Forcona, who was present in Florence in the reconsecration of numerous buildings desired by the pontiff (Alinari, 1935), must have been part of the reforming party of the clergy that headed the monks of Cluny and Vallombrosa, of which Pope Nicholas II with the monk Ildebrando were the most tenacious advocates (Alinari, 1935). Thus, a powerful bishop within the papal court, present at the consecration of numerous buildings between Lazio and Tuscany, may have taken advantage of his position and influence to erect a new cathedral for his city, with strong monastic and northern Italian stylistic influences (Alinari, 1935). Starting from this time and even more from the Norman invasions of the territory, information on Forconian bishops became more detailed and frequent, until arriving at Berardo di Padula in 1252, who would also turn out to be the last bishop before transferring to the diocese of L'Aquila desired by his uncle, Pope Alexander IV, on 20 February 1257 (Signorini, 2012; Marinangeli, 1976-78; Zenodocchio, 1991).

Figure 1. Urban-topographical setting of the study site in relation to neighboring settlements.

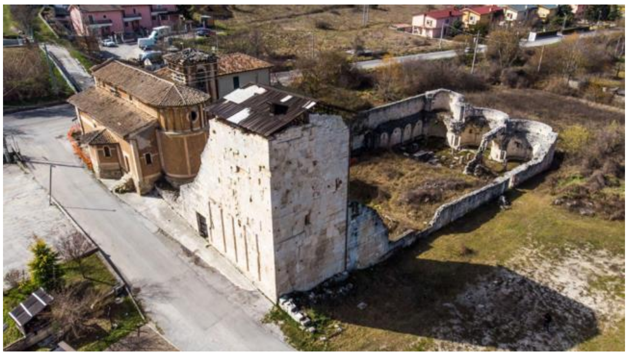

Figure 2. Panoramic view of the Cathedral of San Massimo in Forcona.

3. ARCHAEOLOGICAL ANALYSIS OF CATHEDRAL ARCHITECTURE

The archaeological analysis of the Cathedral of San Massimo in Forcona was carried out by breaking down the material structure of the building into the constructive/destructive actions (USM) that characterized it over time (Boato, 2008; Brogiolo and Cagnana, 2012). During the first inspections carried out on-site in direct contact with the building, a number of hypotheses were developed that were later confirmed by the analysis of the artefact. As a result of these initial reflections, specific analyses of the masonry were carried out for USM that allowed us to reconstruct, albeit in some cases in hypothetical form, the transformations undergone by the church over time. These reflections are described below divided into construction phases.

Phase 1

The first construction phase of the church (fig.3) is localized in the tower and part of the internal and external façade and is characterized by the use of a construction technique made of large, perfectly squared limestone ashlars, arranged in horizontal and parallel rows, with very thin joints. A large part of the tower located in the eastern corner of the structure therefore seems to belong to this phase, to which the northern perimeter wall, with some pilasters present in the inner portion, and, in the western corner, where further pilasters with a semi-pillar define the division of the inner aisles of the structure, are clearly visible, albeit for a small portion. The negative of the roof present in the outer west portion of the tower is also clearly visible, which allows us to understand the original heights of the aisles of the church. Another interesting information comes from the two masonries delimiting the area inside the entrance door to the structure, where archaeological evidence has led to the hypothesis of the presence of a vaulted room, of which the negatives of the arches in the visible portions of the masonry and the infills of their fillings remain, also characterized by a walkable floor located above the vault, also corroborated by some stratigraphic evidence visible on the counter façade (a projecting stone that helps us define the height of the walkable floor and the presence of some squared stones on the counter façade that could represent the sign of an opening in the façade). The presence of the vault, added to the evidence emerging from the analysis of the inner south face, has also made it possible to hypothesize the presence of a second tower on the façade on a French-Germanic-derived "westwerk model", but which in southern and central Italy was particularly popular during the central centuries of the Middle Ages. On the façade, there is also a gutter for draining water located almost at the high end of the tower, which could therefore represent the exit of rainwater discharged from the roof of the nave, thus providing additional data to hypothesize the original heights of the roof pitches of the structure. As for the internal characterization of the building, the structure is divided into three naves with vaults dividing the bays of the side naves. These were connected to the internal perimeter by half-columns, some of which remain visible on the south internal elevation. The back part consisted of a crypt that was accessed through two doors located at the lateral edges of the aisles and a presbytery raised about two metres above the level of the nave, probably reached by a staircase (fig.4).

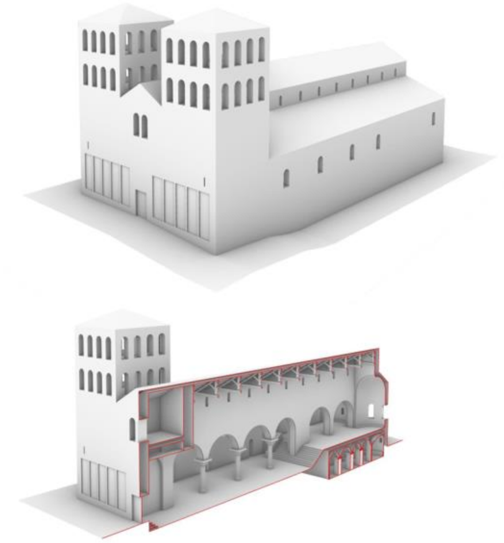

Figure 3. Reconstructive model of the first phase: global view and longitudinal axonometric cutaway.

Figure 4. Graphic elaboration to show the difference in height between the floor levels of the nave (green), the presbytery area (yellow) and the crypt (orange).

Phase 2
The second phase probably corresponds to an extensive reconstruction of the church carried out with a construction technique involving the re-use of material from the first phase, with the addition of *spolia* from both the Classical period, probably from the nearby Roman site of Forcona, or from the early medieval period, perhaps to be connected with the presence of an earlier religious structure located near the cathedral. In this phase, the church probably retained its ancient physiognomy even though it was largely rebuilt, as evidenced by the extensive presence of the aforementioned masonry technique in the basement portions of the outer side perimeters and in part of the inner south perimeter. Unfortunately, there seems to be no evidence of this technique in the upper portions of the structure at present.

Phase 3
Some specific reconstructions made with irregular masonry, with recovered elements from previous phases and with other stone elements are attested in this phase. These operations are aimed at the reconstruction of two main areas: the façade around the entrance gate and the portion of the southern perimeter near the angle cut by the later construction of the church of San Raniero. In the latter area, the installation of an access door to the structure raised above the floor level of the nave is also visible, with the probable construction of an internal staircase for access. The construction technique adopted, and the reconstruction concentrated in only two points of the structure could connect these interventions with some large-scale collapses that affected the building. Given the location of these reconstructions, it cannot be ruled out that the collapse of the second façade tower occurred during this phase.

Phase 4
In this phase we probably witness a profound transformation of the church. The reading of the facings indicates a major internal renovation, marked by the involvement of skilled craftsmen specializing in stone squaring. The construction technique of this phase appears to be characterized by the use of medium-sized, well-squared ashlars of regular dimensions. The following transformations seem to be identifiable in this phase: raising of the entire structure, identifiable both in the southern perimeter and in the façade; reconstruction of the apsidal portion, perhaps in reference to a transformation of the external floor level of the structure; elimination of the vaulting inside the structure and plugging of the fills above, perhaps with the aim of remedying the collapses suffered by the structure in the previous phase.

Phase 5
In this phase there are punctual reconstructions made with stone and bricks that affected the top parts of the bell tower, put in place following obvious collapses.

Phase 6
Progressive abandonment of the structure with the collapse of the roofs and the presbytery.

Phase 7
In this phase can be included the modifications undergone by the structure, by now collapsed and abandoned, following the transformation of the area into a cemetery with the construction of some buildings and rooms located in the internal area close to the façade of the building. In this phase it is also possible to include some restoration work carried out on the structure for conservation purposes.

4. THE 3D INTEGRATED DIGITAL SURVEY OF THE ARCHITECTURAL COMPLEX

The initial stage in the digital documentation of the monument, carried out in parallel of the historical-archaeological analysis operations, involved the execution of an in-depth digital survey using different methodologies and operational techniques. These were integrated with each other both in the acquisition phase and in their results with the aim of obtaining 2D and 3D data at different scales of detail, intended for multidisciplinary applications and analyses. In particular, the main objective of these digital surveys and processing was to provide metric-morphological guidelines and digital support for the development of the stratigraphic analysis of the complex and its architectural-archaeological components (Bertocci and Parrinello, 2015). Through integrated non-invasive acquisition systems such as TLS (Terrestrial Laser Scanning) and SfM (Structure from Motion) photogrammetry, both close-range and by means of UAVs, an extensive descriptive digital database of the architectural complex was developed, consisting of high-poly mapped 3D models, point clouds, architectural drawings and graphic works related to diagnostics.
The main methodology by which the survey operations were conducted consisted in using a TLS technology (Fig. 5). For the acquisition of the metric and morphological data of the study site, a Faro CAM2 Focus M70 instrument, a laser-scanner with phase-difference technology, was used, through which approximately 80 scans were carried out.

Figure 5. TLS instrumentation used and panoramic view of the processed global point cloud.

Parallel to this, a series of SfM photogrammetric survey campaigns were carried out (fig.6), aimed at integrating the metric-morphological data derived from the TLS point cloud with an output capable of representing, through mapped 3D models, information on the appearance and state of conservation of the various architectural elements of the study complex.

For this purpose, various instrumentation and photographic optics were exploited. For the close-range acquisitions, a Canon EOS 1100D SLR and a mirrorless Olympus OM-D EM-1 mark II, both with various lens models, were used, while for the aerophotogrammetric survey, a DJI Mavic Air model UAV device was used.[1] The latter made it possible to obtain a further mapping of the structures in a short timeframe, complete with all those elements that the TLS survey had failed to acquire. The missing data of the wall ridges of the elevations, the upper parts of the façade tower and finally the surrounding orography were thus integrated into the global point cloud by referencing them according to homologous point coordinates extrapolated from it.

Figure 6. Acquisition and processing of SfM photogrammetric data to create a mapped 3D model.

This procedure thus allowed the two digital survey methodologies to be integrated, obtaining both highly metrically accurate mapped 3D models[2] and a global point cloud descriptive of the whole structures (Luhmann et al., 2020).

Using these 3D assets as a geometric basis, a series of wireframe dimensioned graphic drawings of plans, elevations and sections on a scale of 1:50 were then developed, which consequently became the supports for the metric calibration of the photoplans developed from the photogrammetric surveys. Parallel to these drawings, a further graphic support was elaborated for each masonry structure, representing its state of axiality in relation to the vertical plane, the so-called *elevation maps*, by means of which it was not only possible to analyze the deformation state of the masonry, but also to identify any points of discontinuity relative to possible constructive transformations (fig.7).

Figure 7. Creation of a 2D database of graphic designs: CAD, photo plans and elevation maps.

Finally, on the basis of the CAD drawings processed and the results of the archaeological analysis of the construction phases, the three-dimensional reconstruction of the probable original architectural layout was carried out.

The reconstructive 3D model was thus developed using CAD-to-NURBS techniques based on the principles of virtual archaeology (Reilly 1990), which find their foundations in the 2009 London Charter (London Charter, 2009) and the 2011 Principles of Seville (Principles of Seville, 2011), which regulate the criteria of scientific visualization (Bendicho and Grande, 2011).

The workflow for the creation of the reconstructive volumes is in fact an articulated and multidisciplinary process that requires careful review and processing of data (archaeological, historical, architectural etc.) that goes beyond mere visualization. In fact, a strong interpretative contribution must be attributed to it as the 3D models made it possible to discuss and compare the interpretative hypothesis and to verify it through simulation. This is a very important phase that helps to "*imagine the missing parts in order to make sense of what remains*" (Boato, 2008, p.185)

The availability of three-dimensional surveys facilitated the creation of the reconstructive model, ensuring greater accuracy in the setting of volumes and the positioning of architectural elements characterized by rhythms and repetitions such as columns, arches, steps, etc.

In this case, it was decided to avoid a perfectly realistic reconstruction of the entire complex as there was not enough information to detail each architectural and decorative element. Instead, it was preferred to carry out a schematic reconstruction of the volumes that satisfies certain important characteristics for understanding the artefact such as the recognizability of the basic geometry that makes up the architectural elements and the articulation of the spaces.

Since not all reconstructed parts have the same degree of reliability (due to the type of reference source), it was decided to state this interpretative limitation according to a graphic approach (fig.8), already used in other works and simplified here (Ferdani

---

[1] The photographic data acquired from the ground was about 1000, and from drone about 650, the latter taken at an average altitude of about 15 m and an average GSD of 0.11 cm/px.

[2] During the registration between the two 3D assets (point cloud and aerophotogrammetric model), a maximum misalignment error of 0.015 m was found, which for the purposes of the project was considered acceptable.

et a.l, 2023; Demetrescu and Ferdani, 2021), which involves encoding the uncertainty with a palette of colors:

- *Yellow*: reconstructed architecture based on existing archaeological evidence, visible on-site or relocatable according to digital anastylosis processes.
- *Red*: architectures reconstructed on the basis of typological comparisons of contemporary works and neighboring territories or sources interpreted as lacking archaeological evidence.

Figure 8. Reconstructive 3D model (yellow/red) superimposed on descriptive photogrammetric model of the current state (white).

The corpus of 2D and 3D works produced, developed through a critical reading of the data and a discretization of the information massively acquired by the instruments, has been configured, as will be seen, both as a reliable documentation tool for the analysis of historical-archaeological and metric-architectural aspects, but also as a digital support for the creation of virtual fruition systems intended for storytelling and dissemination experiences (Parrinello, 2023).

5. DIGITAL RECONSTRUCTION AND IMMERSIVE VIRTUAL MODEL

Another output realized through the products of the digital site survey was the immersive virtual model, which could be explored in interactive mode (fig. 9). Several steps were necessary to achieve this, each of which was characterized using specific software. This approach made it possible to integrate the geometric data from the scanner with the overall color data obtained through drone photomodelling. Initially, these data are treated separately, since the processing phase requires the creation of a 3D model from the point cloud generated by the laser scanner survey, to be carried out before extracting the color mapping data. This is because the data produced by the laser instrument does not in fact generate a model composed of solid elements, but a very dense set of points each characterized by cartesian coordinates, known as the "point cloud". The latter formed the basis for the subsequent computational process based on triangulating the points of the raw model, with the aim of extrapolating a triangular face model, known as the "mesh model". This process utilizes the Cartesian position of each point in the model, identifying its two nearest points and connecting them through a triangular surface. This cycle is repeated countless times until all points are "joined" across numerous surfaces. This methodology offers the possibility of completely excluding human error, producing an extremely reliable model, albeit with some criticalities. The main criticism concerns the processing times of the various processes, which take many hours or days if not performed on hardware dedicated to this type of processing. To overcome these problems, while not compromising the quality of the final data, it was decided to operate by reducing the number of polygons. To this end, we envisaged using the "Baking" process, an operation that generates a single texture from a single element, reducing the number of polygons for real-time rendering. This technique was used in the San Massimo Cathedral to adapt high-detail models from 3D sculpting software and point cloud scans, creating meshes more suitable for real-time rendering.

Figure 9. Aerial view of the state of the model.

Once the solid model had been acquired with all the required specifications, the texturing phase of the object was carried out. Considering that the model is composed of meshes, it becomes impractical to use ortho-images of the fronts (photoplanes) and map the surfaces directly from them. This is because attributing the corresponding frame to each triangle would be complex and extremely time-consuming. However, this process can easily be performed using any photogrammetry software based on the model generated by the drone survey. In this way, the mesh model and the photogrammetric model are referenced on the same UCS (Universal Coordinate System). By applying the same scale, position and rotation in space to both models, they become perfectly superimposed. Next, the model obtained from photogrammetry is replaced with the high-definition mesh model and the texturization command is applied. This process produces an extremely precise, lightweight model with all color data (fig.10). At this point, it is possible to import the model onto a graphics engine, allowing us to choose a specific way of using the artefact interactively and inserting, if required, further output from specific analyses carried out on-site.

Figure 10. Viewing the model in "player" mode.

With the model of the church of San Massimo, which can be comparable to a repository of information, the graphics engine provided us the opportunity to incorporate interactive elements through the composition of C++ codes. These spots were thus exploited in multiple directions, i.e. by inserting generic information such as descriptions or images of the most significant elements of the structure (e.g. epigraphs and reused architectural elements), or by proposing the choice of different types of

This contribution has been peer-reviewed.
https://doi.org/10.5194/isprs-archives-XLVIII-2-W4-2024-17-2024 | © Author(s) 2024. CC BY 4.0 License.

immersive visualization. In the latter case, it was chosen to transition from the visualization of the current state to that of the reconstruction hypothesis, the latter intentionally realized with a monochrome model as no information on the internal and external colors of the structure was available (fig.11).

Figure 11. Superimposed image of the actual state (left) and assumed reconstruction (right).

It is also possible to include more complex data on the model, such as, for example, dynamic images. In this regard, for the church of San Massimo, an interesting aspect lay in the presence of reused engravings and inscriptions from the Roman and early medieval period from nearby sites. However, these were either not very visible due to the extensive surface degradation of the stone, or difficult to reach as they were located in inaccessible places. To overcome these problems, it was decided to document these elements by means of the RTI (Reflectance Transformation Imaging) methodology. The latter constitutes a computational photographic surveying procedure that acquires the surfaces of an object, enabling its dynamic interactive illumination by the user remotely. Using dedicated algorithms, this technique enhances the shape, surface, and color attributes of the object. RTI's enhancement functions reveal details on the surface that remain obscured during direct observation of the physical object. The use of this methodology has been widely recognized for several years, and its potential is documented through a wide range of specialized publications (Saha et al., 2022). The process of its use consists of several stages and is based on the use of very high-definition static cameras positioned to frame the area under analysis. Subsequently, the same framing is repeated, varying the position of the light in each shot, thus creating a sort of dome around the area of interest. The position of the light is plotted using a spherical marker. The data acquisition phase, just described, requires extremely limited instrumentation and is not dependent on either an electrical or internet connection to be fully effective. These specifications make RTI acquisition one of the most flexible techniques for surveying surfaces, successfully adapting to any situation, even the most difficult conditions. After processing this data within dedicated software, a model of the area under study is generated, incorporating all possible lighting conditions. The resulting virtual model significantly improves the legibility of the elements, both in pictograms and engraved surfaces. In the former case, the different exposure conditions allow the detailed analysis of the surface elements through their variation in refraction. In the case of engravings, on the other hand, there is the opportunity to create depth maps (normal maps) that, appropriately processed, emphasize the clarity of the engravings. For the church of San Massimo, mapping by means of RTI made it possible to document the main decorative architectural elements and the most interesting inscriptions on the structure and to place them within the immersive model in such a way that any user can interactively interrogate them (fig.12).

Figure 12. Comparison between a photographic image (right) and RTI processing of an epigraph on the site (left).

6. SITE ENHANCEMENT AND ONLINE WEB3D APPLICATION

In 2020, the spread of COVID19 brought enormous consequences in the tourism sector with huge economic losses in this and other sectors. It is estimated that, in 2020, there was a drop of about 74% in the number of travelers compared to 2019. The collapse of the tourism sector has given a further boost to digital innovation, with virtual tourism emerging as a viable alternative to physical tourism. This digitization has given rise to new forms of tourism, such as e-tourism, digital tourism, and virtual tourism. The technologies (ICT) form the core of this new mode of traveling: Internet, cloud computing, virtual reality, GIS, modern web technologies - offering new opportunities to maximize the tourism experience, visiting virtual environments online, using different devices, from any remote location in the world. The “traveler” is thus projected into an online digital space, which allows one to move around and explore in complete autonomy, interacting with the virtual environment and interactive contents.

This is the approach employed for designing the web-app created to explore the actual model of the Cathedral of San Massimo in Forcona and its reconstruction[3]. Based on the open-source ATON framework[4] (Fanini et al., 2021), it does not require any installation, allowing the 3D model of the cathedral to be explored interactively on mobile, desktop or immersive VR devices, and to overlay two different reconstructions, using different colors and semi-transparent, superimposed models directly on the actual state.

The exploration of the virtual reconstruction is facilitated by the activation of semantic layers that also allow a conceptual visualization of the reliability of the reconstruction:

- The “*Archaeological*” layer (yellow) displays a schematic reconstruction of certain areas of the church, based on the archaeological evidence on the artefact.
- The “*Typological*” layer (red), on the other hand, shows an elaboration based on typological comparisons obtained by comparing the church of San Massimo with other religious buildings in the L'Aquila area.

These layers can be interactively activated or deactivated through the web-app interface (fig. 13). It is possible to explore the three-dimensional model (3D scene) of the Cathedral either freely or through predefined views using the viewpoint icons on the

---

[3] https://aton.ispc.cnr.it/a/sanmassimo/

[4] https://aton.ispc.cnr.it/site/

bottom. The immersive (WebXR) mode also provides a first-person exploration using the teleport technique (Bozgeyikli et al., 2016) for navigation around the area.

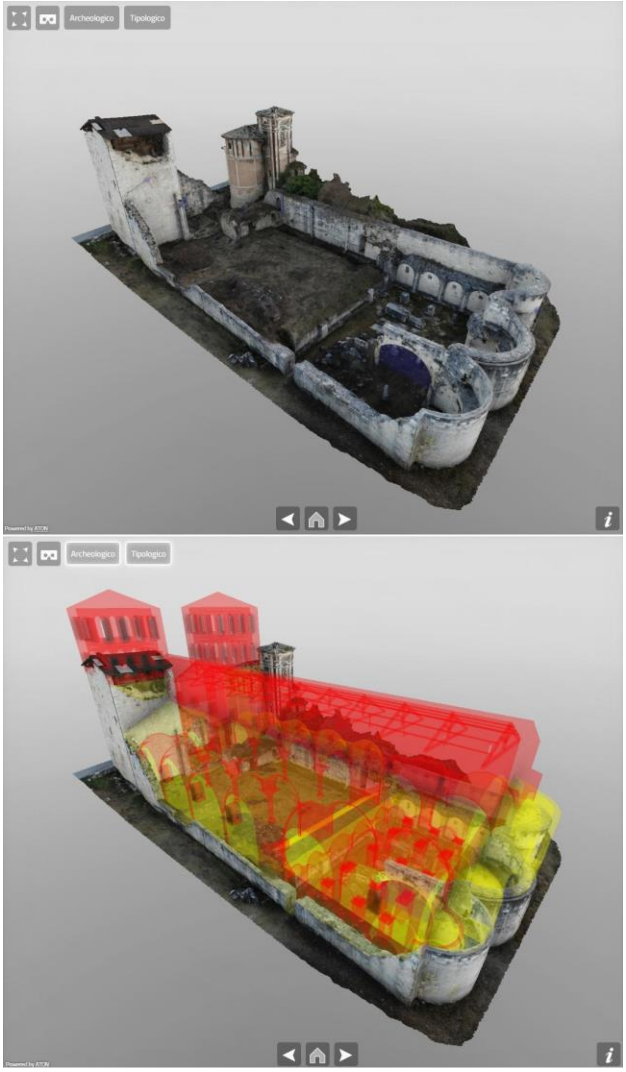

Figure 13. Interactive layers in the Web3D app

Finally, the 3D model was enriched with an additional layer of semantic annotations, derived from the analyses conducted on the site during the archaeological campaigns carried out in 2020 and 2021.

This enrichment was carried out through tools already offered by the framework that allows a restricted team (through authentication) to create, edit or remove annotations or "*semantic shapes*" interactively in the 3D scene. These tools also provide an integrated WYSIWYG editor[5], which allows authenticated professionals, researchers and specialized teams to insert and format text, add images and multimedia content - directly from the browser web-app.

Elements of historical and artistic interest for understanding the model have been identified. These elements are highlighted during navigation through annotations (rendered in the form of illuminated hotspots) that can be activated via mouse, finger (on a smartphone or tablet) or via VR controller (through head-mounted displays).

These 3D annotations have been associated with a series of information that can be viewed by users via activation (fig.14), displaying information panels with detailed texts and images.

Arco_abside

Nella cripta, in un periodo ad oggi sconosciuto ma sicuramente successivo al crollo della struttura della chiesa, venne realizzato un nuovo corpo di fabbrica.
Di questo edificio ad oggi permane un arco che si presenta visibilmente addossato alla muratura absidale

Figure 14. Semantic annotations and associated multimedia content.

7. CONCLUSIONS

Over the years, the collaboration between digital technologies and cultural heritage has strengthened, aiming to make inaccessible places accessible to the general public, recontextualize archaeological objects, and present surprising reconstructions of long-lost contexts. Over time, this collaboration has been increasingly enriched with information and content, until it has become not only a means of dissemination, but also a real scientific tool for those in the field, with the creation of databases full of information that can be consulted online. Through the correct use of ICT (Information and Communication Technology) and by making the most of the potential offered by new communication technologies, it is possible to make the visitor experience increasingly immersive and with a high degree of interaction. Although most users today are ready to use information in digital format through all the means available on the market, some need proper guidance to navigate within the multitude of information available.

The work done on the Cathedral of San Massimo di Forcona represents an example of complex data that can be integrated into a virtual model. The open nature of the model obtained from virtual reconstruction allows the data to be implemented over time, following the evolution of research on the site, and forming a direct and immediate database of the artefact over time.

The proposed example, along with many others of a similar nature, offers the opportunity to expand and preserve knowledge of our artefacts and cultural heritage. It offers the possibility of

---

[5] What You See Is What You Get

consolidating all information in a single repository that is accessible to all, while at the same time contributing to the research and dissemination of lesser-known areas of our country.

ACKNOWLEDGEMENTS

The research presented here is the result of the collective work of the authors, who contributed to the writing of the paragraphs as follows. Paragraph 1: A. Arrighetti; paragraph 2: A. Forgione; paragraph 3: A. Arrighetti; paragraph 4: A. Lumini; paragraph 5: M. Repole; paragraph 6: B. Fanini, D. Ferdani, R. Manganelli Del Fà, S. Pescarin; paragraph 7: A. Arrighetti.
The content and graphic processing of the images were made as follows. Images 1, 2, 3, 4, 5, 6, 7, 8 were made by A. Lumini; images 9, 10, 11, 12 were made by M. Repole; images 13, 14 were made by B. Fanini.

REFERENCES

Alinari, A., 1935. L'antica chiesa cattedrale di San Massimo di Forcona. *Bullettino della Deputazione Abruzzese di Storia Patria*, Anno XXVI, Serie IV, Volume V, 67-80.

Bendicho López-Menchero, V. M., Grande, A., 2011. Hacia una Carta Internacional de Arqueología Virtual. El Borrador SEAV, *Virtual Archaeology Review*, 2(4), 71-75.

Bertocci, S., Parrinello, S., 2015. *Digital Survey and Documentation of the Archaeological and Architectural Sites. Unesco World Heritage List.* Edifir, Florence.

Boato A., 2008. *L'archeologia in architettura: misurazioni, stratigrafie, datazioni, restauro*. Marsilio publisher, Padua.

Bozgeyikli, E., Raij, A., Katkoori, S., Dubey, R., 2016. Point & teleport locomotion technique for virtual reality. *Proceedings of the 2016 annual symposium on computer-human interaction in play*. ACM, New York, 205-216.

Brogiolo, G.P., Cagnana, A, 2012. *Archaeology of architecture. Methods and interpretations*. All'Insegna del Giglio, Sesto Fiorentino.

Brusaporci S., Graziosi F., Franchi F., Maiezza P., Tata, A., 2021. Mixed Reality Experiences for the Historical Storytelling of Cultural Heritage. *From Building Information Modelling to Mixed Reality. Springer Tracts in Civil Engineering*. Cham, Springer, 33-46.

Demetrescu, E., Ferdani, D., 2021. From field archaeology to virtual reconstruction: A five steps method using the extended matrix. *Applied Sciences,* 11(11), 5206.

Fanini, B., Ferdani, D., Demetrescu, E., Berto, S., D'Annibale, E., 2021. ATON: An open-source framework for creating immersive, collaborative and liquid web-apps for cultural heritage. *Applied Sciences,* 11(22), 11062.

Ferdani, D., Demetrescu, E. Cavalieri, M., 2023. Interpreting and Visualizing the Past Through Virtual Archaeology: From Site to Museum Experience. *Digital Restoration and Virtual Reconstructions: Case Studies and Compared Experiences for Cultural Heritage*. Springer International Publishing, Cham, 3-18.

Giuntella, A.M., 2003. The Duchy of Spoleto. Persistence and transformations in the territorial structure (Abruzzo and Sabina), in I Longobardi dei ducati di Spoleto e Benevento. *Proceedings of the 16th International Congress of Study on the High Middle Ages*. Spoleto, 763-799.

London Charter, 2009. *London charter for Computer-Based Visualization of Cultural Heritage,* http://www.londoncharter.org/.

Luhmann, T., Chizhova, M., Gorkovchuk, D., 2020. Fusion of UAV and Terrestrial Photogrammetry with Laser Scanning for 3D Reconstruction of Historic Churches in Georgia. *Drones* 2020, 4, 53.

Marinangeli, G., 1976-78. Alexander IV and L'Aquila. *Bullettino della Deputazione Abruzzese di Storia Patria*, Year LXVI-LXVIII, 389-451.

Miliario, E., 1995. *Men, lands and roads. Aspetti dell'Italia centroappenninica fra Antichità e Alto Medioevo*. Edipuglia, Bari.

Muratori, L.A., 1742. *Annals of Italy*. Giovambattista Pasquali, Milan.

Pani Ermini, L., 1972. Contributions to the history of the dioceses of Amiternum, Forcona and Valva in the early Middle Ages. *Rendiconti. Pontificia Accademia Romana di Archeologia,* 44, 257-274.

Parrinello, S., 2023. Digital narratives for the memory of archaeological excavation. *ARSINOE 3D: Rediscovery of a lost city in Greco-Roman Egypt.* Florence University Press Florence, 154-171.

Principle Of Seville, 2011. *International Principle of Virtual Archaeology*, http://www.sevilleprinciples.com/.

Redi, F., De Iure, A., Siena, E., 2012. Abruzzo between Goths and Byzantines. Updates in archaeological research. *The transformation of the Roman world and the great migrations. New peoples from northern and central-eastern Europe to the shores of the Mediterranean.* Tavolario, Cimitile, 195-216.

Reilly, P., 1990. March. Towards a virtual archaeology. *Computer Applications in Archaeology*. Oxford, British Archaeological Reports, 133-139.

Saha, S., Siatou, A., Mansouri, A., 2022. Supervised segmentation of RTI appearance attributes for change detection on cultural heritage. *Herit Sci*, 10, 173. https://doi.org/10.1186/s40494-022-00813-3.

Signorini, A., 2012. *La diocesi dell'Aquila descritta ed illustrata*. Nabu Press, Florence (reprint).

Zenodocchio S., 1991. Saggio di toponomastica forconese dai regesti farfensi. *Bullettino della Deputazione Abruzzese di Storia Patria*, LXXXI, 217- 284.