# Survey and 3D reconstruction of the St. Orso capitals in Aosta, through three-focal photogrammetry

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*Abstract*— **This paper describes the methodology adopted and the results obtained during the 3D documentation of the medieval capitals of St. Orso Collegiate Church, in Aosta, for reference and digital archiving. This task has been carried out through low cost technology entirely based on digital scanning of high quality images applying stereo-photogrammetric principles. This technology allows to obtain point clouds with RGB information and geometries at different levels of complexity, processing a number of images taken with a limited set of constraints, with the use of a special acquisition equipment and through an image matching algorithm. Issue in this research was to obtain the accurate 3D information required to build models of artifacts of a such heritage importance, with a high degree of complexity. In future the 3D model will contribute to create a spatial Information System which will assist conservation and restoration activities on the one hand and will be used for tourist information inside the St. Orso Collegiate Church on the other.**

***Keywords-documentation; photogrammetry; three focal geometry; points clouds; digital models; Cultural Heritage***

## I. Introduction

Different new survey technologies play a leading role in the process of Cultural Heritage knowledge and documentation so far they are finalized to the acquisition of geometric data that can deeply describe features and peculiarities of historical monuments and that are really necessary for programming their conservative interventions. Moreover the demand for 3D models of ancient monuments or historical-artistical artifacts is continuously growing in the field of archaeological and architectural applications; public bodies, engaged in safeguard, preservation and valorization of Cultural Heritage frequently require 3D survey and reconstructions of each monuments, in order to avail themselves of geometric data digital archives not only for documentary and cataloguing reasons but also for the exploitation and transfer of Cultural Heritage knowledge to the general public [1] [2].

The two main sources that can provide detailed and reliable 3D models are laser scanning through range-based techniques and photogrammetry through image-based modelling. Among the plenty of works so far presented the use of laser scanning for Cultural Heritage survey seems to aim towards a monopoly in the 3D modelling pipeline [3]. Laser scanner technology permits detailed 3D description of the artifacts geometry, without subjective interpretation, nevertheless, it is often very expensive, requiring professional skills and a great amount of post processing work. Recently, on the other hand, the development of digital photogrammetric systems allows the definition of 3D visualization and navigation environments within which the data referring to geometric consistency are combined, without loss of rigor, with photos qualitative, morphological and colour information [4].

This paper focuses on the description of a photogrammetry-based survey technology for point clouds and 3D models acquisition only from digital images processing. The occasion to analyze advantages and limits of this new survey technology was represented by a research project goal-oriented to a 3D documentation of the medieval capitals of the cloister of St. Orso Collegiate Church in Aosta, and carried out by the Institute for Technology Applied to Cultural Heritage of the National Research Council and by the Superintendence for Cultural and Environmental Heritage of the Valle d'Aosta.

The Public Administration was determined to create a digital archive of the capitals, endowed with the scientific reliable and accurate range measurement of each of them, that could be extremely useful for helping decay condition analyses or historical-critical investigations and that could be utilized for allowing their eventual reconstruction in case of physical and structural damage. An accidental episode already occurred in the 1997: one coupled capital of the western gallery of the cloister was stolen by vandals. The stolen part of the capital has then been replaced with a copy, as much as possible similar to the original and obtained from the analysis of the historical photographic documentation available.

## II. Preliminary remarks

### A. *The case study description*

The St. Orso Collegiate Church complex, which is one of the most important in the Alps, includes the Church of Saints Peter and Orso, the isolated and majestic bell-tower, the marvellous cloister and the Renaissance priory. The St. Orso cloister (Fig. 1), a real Romanesque masterpiece, was

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Figure 1. The medieval cloister of the St. Orso Collegiate Church.

probably completed in 1133 as confirmed by an inscription on one of the decorated capitals in the south gallery of the cloister (capital n. 36, according to Berton numeration [5]). It is rectangular in shape with sides that measure respectively 19.50 and 10.70 meters, and consists nowadays of 40 columns and of 37 original Romanesque marble capitals, but it originally included even more than that. In fact at the end of the XVIII century the cloister eastern gallery was pulled down and replaced with four domical vaults, three new columns and three new capitals decorated with vegetal motifs. Consequently some of the original capitals have got lost; four of them came in the Civic Museum of Turin, where they are still conserved [6].

The St. Orso capitals, all different one from another, are mostly decorated with figures or narrative scenes. The historiated capitals represent subjects and stories relevant both to the Old Testament (Abraham, Nebuchadnesser, Job, Jacob) and to the New Testament (Christ's childhood and Apostles' lives), as well as relevant to the foundation of the Augustinian community and to the life and miracles of the patron St. Orso.

From stylistic point of view, the capitals are characterized by a great simplicity of the compositions and reveal a typical taste for details and relief techniques. The figures, fully round sculpted, show up well against the capital background, setting up unbroken narrative scenes specified even through several inscriptions. The capitals, originally carved out of white marble, were covered for protective reasons with a dark varnish already present at the beginning of the XVII century; this black coating allowed to relatively well preserve along the capitals, even if it had deeply changed their original looking.

### B. Guidelines

The project aimed to achieve a complete cloister capitals documentation, through the reconstruction of detailed 3D digital models that had to be interactively explored in suitable environments in order to allow interdisciplinary analysis of the artifacts.

The documentation created has to become a research instrument, usable by conservators, archaeologists and researchers, in order to increase historical-artistical knowledge of monumental Romanesque sculpture, to allow the assessment of capitals state of conservation and to identify the eventual necessity of restoration interventions.

Considering project aims and most of all the singularity and geometry complexity of the capitals, that can be adequately described only through a 3D representation, the survey results have to fulfil some specific qualifications:

- to provide detailed metrical and morphological information, with particular reference to construction peculiarities, in order to allow stylistic investigations or physical and structural pathologies analysis;
- to provide qualitative information through the detailed recording of actual colour values, in order to help the identification of material decay and alterations;
- to assure a reliable geometry documentation, with so great levels of precision and accuracy, to allow the original capitals replacement with solid prototyping copies, in case of damage or conservation necessities;
- to share in the experimentation of new documentation methodologies based on digital surveying techniques.

All these aspects led to the decision of adopting a non conventional low cost technology that, even in an experimental environment, would guarantee that the two main aspects of geometry and colour information would be provided by one single type of equipment, with the best optimization of acquisition and processing time and without conflicting with the need of survey precision and quality. An innovative comparatively low cost technology entirely based on digital scanning of multi-view high quality images sequences, through the application of stereo-photogrammetric principles, was experimented; it allows images capture and RGB point clouds extraction from images pixels, thanks to a specific algorithm for image processing and feature matching. Compared to other range-based techniques, even more expensive, like e.g. laser scanner based on optical triangulation, this technology, although warranting similar reliable results within millimeters accuracy, allows to optimize acquisition time considering that, since it is based on images treatment, it makes possible the simultaneous spatial and colour data capture.

All these aspects, together with the comparatively low cost of the recording device permitted to keep low the global cost of the survey activities; in this way it is possible to offer also to small Public Administrations or local museums the opportunity to plan documentation, conservation and exploitation activities of their own Cultural Heritage, otherwise not always possible if more expensive technologies and methodologies, as laser-scanner, are involved. Frequently economic inadequacies lead the authorities engaged in preservation of Cultural Heritage to employ the most part of the financial resources to face urgent restoration operations, reducing the economical resource available for architectural and archaeological artifacts documentation, study and valorization; that question us on the ethical responsibilities of the development of not too expensive data capture and digitization technologies for increasing Cultural Heritage knowledge.

## III. Methodology and Techniques

Concerning capitals survey, the photogrammetry-based survey technology adopted is ZScan Survey System (manufactured by Menci Software of Arezzo): it can be

Figure 2. ZScan and other equipments used for data acquisition.

used to obtain RGB point clouds and relative 3D models, at different levels of complexity, starting from the treatment of a number of images, taken with a limited set of constraints, through the use of a special acquisition equipment, and processed in a specific software, through the application of image matching algorithm. The acquisition equipment consists of a calibrated aluminium bar, which can be easily mounted on a photographic tripod, and which is provided with a small trolley for supporting a digital camera also calibrated (Fig. 2). Both the bar and the digital camera calibration parameters, that have to be send to the software for data processing, are necessary in order to allow the spatial reconstruction of camera centre position and to know the distortions due to the optics employed.

The trolley allows to move and to secure the camera in different fixed positions on the bar in order to acquire sequences of images of the same object from different angle-shot. To produce a single 3D model, a sequence of three images, has to be taken from the left to the right, shifting the camera along the bar. The left and the right shots must be symmetric compared to the middle of the bar, and the distance between them (the baseline) has to be carefully evaluated in relation to the optimal distance of the camera from the object, survey accuracy and level of detail required. There is no need of topographical support points, in order to create the single 3D model. However it is possible to make use of ground control points, during image processing, in order to geo-referencing the single point clouds, in relation to a global datum system, and then to facilitate point clouds registration necessary for producing a final complete 3D model of the surveyed object.

The systems satisfies characteristics of great flexibility and ease of use and guarantees, at the same time, accuracy of the geometric data acquired. However, using an image processing algorithm for 3D reconstruction, the system has some limits of application in relation to the characteristics of measured object surfaces. It reveals limits in the 3D point cloud reconstruction of surfaces endowed with homogeneous colours, repetitive patters or high reflective materials.

## IV. 3D CAPITALS DOCUMENTATION

### *A. Data acquisition*

The survey of the capitals of St. Orso cloister, has been the chance to enlighten and solve many of the critical aspects of the application of ZScan system owed mainly to the image capture as for example: planning the shots in order to cover all the hidden parts of the artifacts; light, shadows and color control; color balance and equalization between different shots.

Capitals represents a challenging task for 3D photorealistic modeling goal, given their complexity both from the geometric and colorimetric point of view: on the one hand the presence of recesses and partially occluded surfaces, determined by the different decorative figure characterized by areas with high surface curvature, makes particularly hard the complete reconstruction of their shape and physical features; on the other hand both the dark patina on capitals surfaces and the high light contrast between the cloister galleries and the small square courtyard, hinder the homogenous photographic recording of multi-view image sequence necessary for the output of a realistic 3D model texture.

For the complete image coverage of each capitals, several sequences of three images had to be taken, changing many times the bar position all around it. The great positional and angular flexibility provided by the acquisition equipment and the possibility to easily change the standoff distance, allow to overcome difficulties in data capture due to the spatial restrictions between two different columns. Each capital was initially acquired with a vision axis perfectly orthogonal to the surface, making 8 sequence of three images, 4 for the front faces and 4 for the angles. We adopted an overlap between two subsequent images triplet of about 30% in order to allow the global registration of the single point cloud obtained.

Moreover, in order to acquire the most part of the undercuts or covered parts of the decorative figures, for each instrument positions we repeated the photographic acquisition adopting other two different angle of inclination for the camera, with a catch axis inclined towards the top and then inclined towards the bottom, paying attention to adopt a rotation angle of no more than 15° with respect to the vertical, in order to minimize photographic deformations. In the aggregate, with the exception of the coupled capitals of the western cloister gallery, a total of 72 high resolution pictures have been taken for each capital, using a Nikon D-200 digital camera (CCD sensor of 10.2 megapixel, 24mm lens used), calibrated in a UNI-Normal certified laboratory.

The acquisition of the coupled capitals have required more time and effort, considering the problem of different focusing; we have planned 16 different instruments positions in order to be sure of correctly documenting each part of the capital and to assure the linking between the two capitals, for a total of 144 images.

In order to obtain a great survey precision and an high representation detail, the shots were taken with a camera distance of only 70 cm from the capitals, with a subsequent baseline of only 10 cm; these configuration allows to achieve a theoretical depth accuracy of approximately 0.4 mm. Moreover we did our best to acquire the images sequences in homogeneous lighting conditions for optimizing the quality of the overall models and, above all, for avoiding big light changes in intensity and direction between one shot and another along the same bar position. Different tries were made in photos capture before implementing the survey: only with ambient light in a

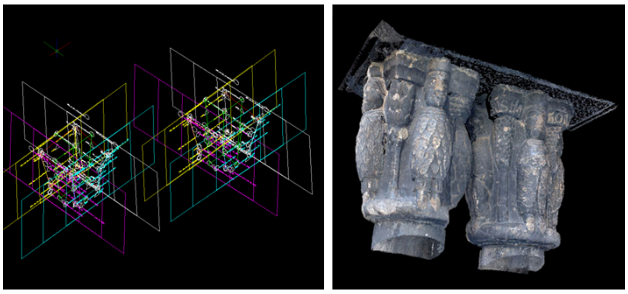

Figure 3. Topographic survey for the accurancy control of a coupled capital 3D model reconstruction.

Figure 5. Example of an RGB point cloud (left) and a texturized model (right) obtained processing a triple sequences of images.

cloudy day; combining natural and artificial lighting; during the night hours using only artificial environment lighting. The best results were achieved in daylight with the support of a special set of two professional led lights (5000 K) and with the use of reflecting panels, so as to create a controlled and diffuse lighting all around the capitals important for avoiding loss of data and any possible specular reflection or shades on surfaces (Fig. 2).

Since ZScan systems doesn't require topographical support the topographic acquisition, performed with a total laser station, wasn't particularly onerous, in term of working times and thus of cost: for each capital only few significant natural architectural points were chosen as support points and acquired for having the possibility of geo-referencing the final models. Nevertheless a detailed topographic survey has been exploited for one of the 37 capitals (Fig.3) in order to finally control the accuracy of the registration process and verify the methodology adopted, since we wanted that the registration process residuals would be equal or better than the geometric precision required.

### *B. Data processing*

Data processing has been carried out through the use of two dedicated software that are part of ZScan survey system.

The first software, is necessary for extracting from each sequences of three images acquired a single point cloud that contains both spatial and color information, i.e. xyz co-ordinates and RGB values for color rendering (Fig. 4). Once having controlled, and eventually corrected, the chromatic equalization between all the different shots, through the use of an image processing commercial software (Photoshop), the three images of each scan position and the relevant acquisition parameters (the baseline adopted and the calibration file of the lens used) can be rapidly loaded in the software.

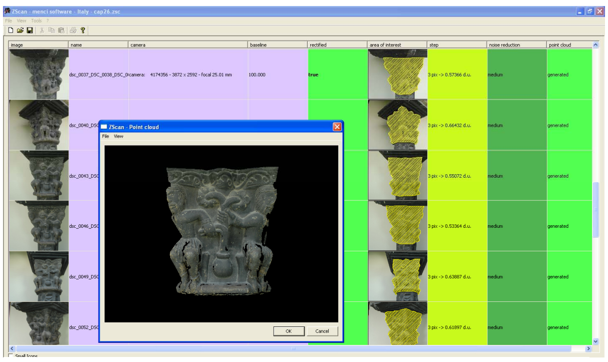

Figure 4. Creation of RGB point cloud from each images triplet.

The subsequent procedure for RGB point clouds extraction, consists of four main steps: images rectification, through the application of trinocular rectification and feature matching, in order to eliminate geometrical and optical distortion; selection of the image areas of interest (AOI) that have to be processed; definition of the step resolution value, measured in pixel unit; production of a point cloud relevant to each group of three images, through the application a sophisticated algorithm for image processing. Moreover, contextually to the point cloud production, the software allows to automatically create a texturized triangulated surface, through a triangulation process of the point cloud (Fig. 5).

According to the survey precision and to the representation detail needed, a step resolution value of 3 pixel was adopted for the elaboration of each three images sequences, corresponding to 0.3 mm point to point sample spacing on the created point cloud. At the end of this first part of data processing, for each capital, we achieved 24 high quality RGB point cloud (each one samples around 0.4 millions of points), with the relative detailed photo-realistic 3D model.

In order to achieve a complete and non-redundant 3D representation of the capitals other two processing steps were performed using the second dedicated software provided with the survey system: the global registration of the single 3D models, obtained from every triple sequence of images, and the point clouds cleaning, for removing all the overlapping parts and redundant data. The software allows to perform two types of registration process: a first semi-automatic registration, achieved through operator recognition and collimation of homologues significant control points between two different point clouds; a second automatic registration, performed using an ICP algorithm, for refining the first alignment (Fig. 6).

These procedures were both used, for each overlapping models, checking errors propagation during all the

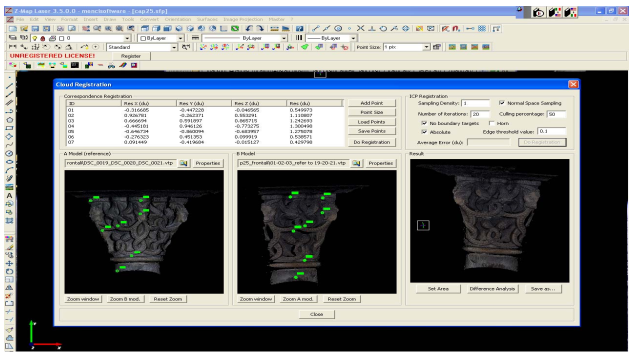

Figure 6. Registation of two different point cloud.

Figure 7. Example of a capital final 3D model(photo-realistic rendering on the left and triangulated mesh representation on the right).

orientation process; the average accuracy obtained has been of 0.2 mm. The final merging process of all the models, for building a single non-redundant mesh, was carried out in another standard software for scanner laser data processing, Rapidform by INUS Technology Inc. Before starting with the global merging several mesh editing process has been performed in order to improve the quality of reconstructed meshes. Concerning the capitals final models the number of triangles can change between 5.3 and 6.3 millions according to capital dimension and surfaces complexity (Fig. 7).

According to the research aim a final global 3D model of each capital has been provided. Each 3D digital model can be interactively explored by researchers and technician experts of the public administration, through the use of an appropriate software, that allow different types of model visualization (RGB point clouds, grey shaded models, wireframe rendering, photo-realistic rendering), becoming a great tool for analysis, investigation, and scientific control. On the one hand the geometric reliability of the models permits to investigate in capitals constructive and morphological peculiarities, with a very high degree of accuracy, allowing additional quick and automatic geometric elaborations (e.g. extrapolations of horizontal and vertical sections, measurements, etc.), necessary for inquiring into the presence of possible artifacts static damage. On the other hand the color information, provided by the RGB point clouds or by textured representation, allow to perform directly on the 3D models, historical-critical analysis, reports of the decay pathologies, hypothesis in order to program restoration interventions.

## V. Project developments and future works

### A. *Collaboration to the CENOBIUM Project*

The geometric documentation produced was utilized also within another research project, the CENOBIUM project. One of the main goals of this project is indeed the realization of a multimedia presentation, available on the internet, of a selected group of important Romanesque capital-cycles, in medieval cloisters of the Mediterranean Region, starting from the reconstruction of detailed 3D digital models of the capitals, integrated through color mapping with the 2D information of high resolution photographs [7].

The project started in the 2006 with the laser scanning documentation of the capitals of Monreale cloister in Sicily [8], through the cooperation of the two main partners of the project: the Kunsthistorisches Institut in Florence (Max-Planck-Institut) and the Visual Computer Lab at the Institute of Information Science and Technology

Figure 8. 3D model of capital provided with high quality color information (in cooperation with the Kunsthistorisches Institut in Florenz, and the Visual Computing Lab of ISTI-CNR in Pisa).

“Alessandro Faedo” of the National Research Council (ISTI- CNR). Since they wished to document also the capitals of St. Orso Collegiate Church, instead of repeating data acquisition, they asked us to cooperate to this part of the project, making our 3D geometric data available and contributing to their further processing.

The possibility of colour mapping a group of St. Orso capitals geometric models (the most significant from an artistic point of view) with high resolution digital images, acquired by the Kunsthistorisches Institut through the use of a Sinar P3 digital camera integrated with the digital backs Sinarback 54 H and Sinarback eMotion 22 (both of them with a resolution of 22 million pixel), has been indeed verified. To this purpose and in order to obtain 3D models similar for characteristics and details to the ones already produced for the Monreale cloister documentation, we started a new processing phase of the range data acquired with ZScan technology, through the use of ISTI CNR 3D modelling tools (MeshAlign, MeshMerge and MeshLab tools). The new final models produced were colour mapped by the Visual Computer Lab, using an innovative all its own tool, achieving detailed photorealistic models that allow a complete description of capitals geometric, chromatic and material information (Fig. 8). This further experimentation allowed us to verify the very flexibility of the survey technology adopted, whose data acquired can be easily exported and processed also with other common post-processing and 3D modelling software. Moreover we were able to check that the quality of the geometric results obtained can be easily compared, in terms of surveyed number of points, reliability and accuracy, to those ones achievable through the use the more expensive laser scanner technology.

### B. *An Information System for cloister conservation*

Starting from this experience we hit upon the idea of creating an interactive and multi-scale environment in which it would be possible to explore the high-resolution digital models of each capitals, represented and replaced in their original architectural and conceptual contexts, that is the 3D virtual reconstruction of the global cloister. Therefore the capitals 3D documentation must be considered as the first step for a multi-scale survey project of the entire St. Orso Collegiate Church cloister and for the creation of a spatial Information System in which all the acquired historical-critical or thecnical information could be organized in layers of deeper structural and iconographical complexity and detail, in order to support

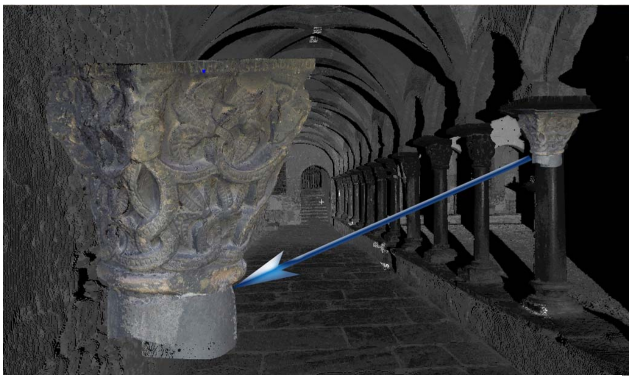

Figure 9. Datasets acquired with different technologies at different LOD geo-referenced in an homogenous environment.

further conservation and restoration activities on the cloister. Inside this Information System, in fact, it will be possible to load and continuously update the datasets and multimedia information relevant to structures modifications or decay conditions, acquired with different technologies and methodologies, and geo-referenced in an homogeneous digital environment in order to provide an instrument of analysis for expert users and researchers.

For achieving such a vast program the global topographic, photogrammetric and time-of-flight laser scanner survey of the cloister has been started (Fig. 9), aimed to either generate an holistic 3D model of the entire cloister, either to create a platform for the future organization of spatially correlated data on the monument.

A lite version of the created Information Systems could be finally employed for the valorization of St. Orso cloister, allowing visitors and no expert users to delight in a museum presentation and a digital fruition of the medieval cloister. Special kiosks, installed nearby the cloister, could allow the public to enter the Information System and to perform a virtual exploration of the monument and of his extraordinary historical-artistical artifacts, with level of subsequent zooming to "approach the object", made possible by the different geometric and photographic level of detail of the models (Fig. 9). This virtual interactive 3D environment could focus visitors attention on the capitals, making their visit of the cloister a different experience and helping their comprehension of the historical and symbolic value of each capitals. Moreover, in order to create a reconstructive hypothesis of the original cloister configuration and to clarify the original iconographic theme developed by the capitals figures and narrative scenes, we would like to place again, inside the virtual cloister reconstruction, also the 3D models of the four capitals nowadays preserved in the Civic Museum of Turin. According to historical-critical investigations, in fact, the iconographic theme developed by capitals-cycle had to deal with the humanity redemption through Jesus Christ Incarnation and consequently had to start with one of the capitals of the Civic Museum of Turin that symbolize human Original Sin.

## VI. CONCLUSIONS

The project of the documentation of the St. Orso medieval sculpted capitals has been a valid occasion to experiment the application of a low cost innovative survey system for range data extraction and 3D model reconstruction, based only on image capture and processing. The technology used allowed to acquire high quality range data of the capitals, similar in terms of resolution and precision to those ones obtainable with the use of laser scanning, and extremely detailed both in terms of spatial and colour information since it permits to achieve RGB point cloud and photo-realistic models, in which morphological details and components materials can be easily showed.

The obtained 3D models are in good agreement with project requirements. They represent a capitals overview, a tool for investigations, on which historians or conservation experts could perform historical-critical hypothesis, geometric analysis, reports of the decay pathologies, programs for the managing of restoration interventions. Moreover the records completeness achieved provides the Public Administration with a complete archive of capitals range measurements and visual information, that could furnish a reliable and detailed documentation in case of their physical or structural damage. The same 3D models will contribute to the creation of a global Information System of the cloister, the detail of which will be subject of other future works, that will support conservation and restoration activities, on the one hand, and will allow valorization process of the St. Orso Collegiate Church, on the other, since it could be used as tourist information tool inside the cloister.

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