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SCAN-TO-BIM AND SEGMENTATION PROCESSES FOR THE CONSERVATION OF CULTURAL HERITAGE. A WORKFLOW PROPOSAL

The ongoing technological development in the AEC sector is also radically influencing the area of cultural heritage, which is notoriously very conservative. The processes of digitisation of the historical architecture and archaeological heritage are giving great pulse to projects and programmes aimed at physical and cultural accessibility, conservation, tourist attractiveness, dissemination and scientific research with positive effects in terms of enhancement and visibility.
3D survey, H-BIM and scan-to-BIM processes, Machine Learning and Artificial Intelligence applications are contributing to a methodological and design approach revolution referred to cultural heritage.
This paper shows a workflow related to the analysis of the degradation of ancient surfaces and its digital transposition on parametric models through the semi-automatic segmentation of high-resolution images. The goal is to provide a useful tool for populating ultra-specialized information in BIM environment for maintenance and restoration activities.
The case study on which the methodology was applied is a part of the western fortifications of the Aragonese Castle of Ischia; these protect Piazza d'Armi, are overlooking the sea and incessantly subjected to the corrosive actions of the wind, salt and rain. The object has been identified for its intrinsic inaccessibility and the consequent difficulties to intervene with traditional survey and analysis of degradation approaches.
The research is part of a scientific collaboration agreement between the Department of Civil, Building and Environmental Engineering of the University of Naples Federico II and the Aragonese Castle s.a.s. which is producing studies and research on architectural emergencies inside the fortified citadel.

Keywords:
digital survey, H-BIM, surface restoration, machine learning, CH management

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INTRODUCTION

The planning interventions for maintenance or restoration on complex artifacts from historical and constructive viewpoints, especially those related to cultural heritage, cannot overlook a thorough critical analysis of the geometries and the transformations they have undergone. A macroscopic reading of architecture and a detailed investigation into specific elements enable the definition of clear intervention methodologies based on scientific criteria [De Feo, 2023].
Digital technologies related to the discipline of Drawing, which have been continuously evolving for almost two decades, are being employed very effectively in the field of architectural surveying, informative parametric modeling, and applications of Machine Learning (ML), Extended Reality, and Artificial Intelligence.
The digitization of architectural heritage not only offers the possibility of approaching them from multiple perspectives through unprecedented forms of interpretation and understanding [Inzerillo et al., 2016] but also allows for evaluations, analyses, and research to be conducted without necessarily visiting the site, thus enabling interaction at any time and from any location [D'Agostino et al., 2023]. The 'digital copy' of the real building, if done correctly, assumes informational and cognitive value comparable to that of the object itself, representing its material characteristics and conservation status [Linee guida ..., 2022].
Many activities concerning historical artifacts – such as planning interventions, tourist-cultural valorization, or scientific research – are often hindered by the nature of the locations they are situated or by the configuration of the artifacts themselves. A striking example of the aforementioned is provided by the Aragonese Castle of Ischia (a part of which is the case study of this paper), whose accessibility is greatly limited on one side by the intrinsic nature of the island of Ischia and on the other by the nature of the fortified citadel (Fig. 1) [D'Auria, 2024].
Also for these reasons, the digitization of cultural heritage has become a priority for many countries,

Fig. 1 - The islet that houses the fortified citadel

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making it necessary to define guidelines and best practices in order to attempt to standardize infographic languages and technical procedures.
This digital revolution has also stimulated new attitudes towards the conservation, preservation, valorization, and understanding of architectures. What has been relatively to the process of digitizing cultural heritage has led, for example, to the development of systems within the field of Artificial Intelligence (AI), connected to that of Augmented Reality (AR) [Croce et al, 2023].
In this sense, this contribution shows a workflow related to the analysis of degradation of ancient surfaces and its digital transposition onto BIM models through semi-automatic segmentation of high-resolution images. The goal is to provide a useful tool for populating ultra-specialized information in H-BIM environment for maintenance and restoration purposes.
The process is based on the following steps: laser scanning and photogrammetric survey of the analyzed artifact; scan-to-BIM modeling; editing of high-resolution orthoimages of degraded surfaces; training of ML algorithms for the automatic recognition of some degradation phenomena; production of infographic outputs of degradation survey; integration of results into the BIM environment.

Fig. 2 - A section of the southern fortifications

The case study on which the methodology has been applied is a section of the western fortifications of the Aragonese Castle of Ischia, those protecting Piazza d'Armi, which are overlooking the sea and constantly subjected to the corrosive actions of wind, saltwater, and rainwater (Fig. 2).
The object has been selected due to its intrinsic inaccessibility and the consequent difficulties in intervening with a traditional approach to surveying and analyzing degradation. The research is part of a scientific collaboration agreement between the Department of Civil, Building and Environmental Engineering of the University of Naples Federico II and the Castello Aragonese s.a.s., which is producing studies and research on the buildings hosted within the fortified citadel, related to the analysis of historical-constructive transformations, improvement of physical and cultural accessibility of places and architectures, and intervention protocols for conservation and restoration.
This research highlights the strengths and weaknesses of each step of the proposed workflow and draws attention to improvable aspects such as, for example, interoperability between computer processes and languages, also considering the constant regulatory updates affecting this cultural domain [D'Agostino & Antuono, 2022]. The work aims to propose a pragmatic approach that fits into the current debate on the effective use of semi-automatic processes for parametric modeling in the reverse-engineering process applied to historical architecture. An approach, therefore, that in the service of cultural heritage can be extended and used in the chain of recovery and restoration works, without forgetting the (a)typical nature of information of existing historical constructions, characterized by a well-known variability of their geometric features and the informational fragmentation that often affects the digitization of architectural artifacts.

THE CASE STUDY

The case study identified for the application of the proposed workflow is a stretch of the Aragonese fortifications of the Castle of Ischia. The fortified citadel stands on a granite rock located in the easternmost part of the island of Ischia, the largest island in the Gulf of Naples. The rock was formed between 130 and 150 A.D. when the strip of land that linked the original promontory to the island was completely submerged by the sea sinking as a result of volcanic and telluric phenomena that greatly disturbed Ischia.
Due to its strategic position in the Gulf of Naples, Ischia has always been an important geopolitical point of reference. For this reason, it was often fought over by the people who sailed the Mediterranean Sea, and through the centuries it has experienced, whether directly or indirectly, all the vicissitudes of the nearby city of Naples.
The castle, as we know it today, began to expand and become a fortified town following the eruption of the volcano Arso in 1301. On that date, many people moved to the islet, which had not been damaged. From that moment, the local noble families began to erect public and private buildings and the population began to build villages of fishermen and farmers.
In the first half of 15th century Alfonso V, king of Aragon, led the implementation of a plan aimed at making the fortified citadel a true stronghold in times of war and a royal residence in times of peace. The monarch enlisted artists and urban planning experts to ensure that the castle would take on the features he envisaged. Till then, as-

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cent to the stronghold had been via an external route, Alfonso had an immense tunnel carved into the rock, barred by five gates and equipped with loopholes that provided illumination to the entire route and served as a means of defence against possible attackers (Fig. 3).
He had retaining walls erected along the cliffs overlooking the sea, placed rocks, set up iron gates, and created a connecting network between the towers. To defend the keep, he provided a deep moat. The bridge of Angevin origin that connected the islet to the insula major was repaired and strengthened [D'Ascia, 1867].
The plan of the fortifications took the form surveyed by the engineer Benvenuto Tortelli in the second half of the 16th century. In the plan are well drawn also the walls along the Piazza d'Armi, object of this work (Fig. 4).
From 1809, with the wars between the Anglo-Bourbons and the French, the castle began its slow decline with the consequent abandonment of lands and homes. At the beginning of 1900, the lawyer Nicola Mattera bought the castle at a public auction and from that moment began the work of safety, maintenance and restoration of all the buildings and paths in the fortified citadel.
Nowadays the Aragones Castle of Ischia is an open-air monument open to the public, which also hosts cultural events and art exhibitions of international level. Due to its particular exposure to atmospheric agents and sea corrosion, the fortified citadel needs constant maintenance and restoration works. In this paper, therefore, is described the operating methodology developed to define a design analysis processes BIM-based that facilitates the identification and organization of interventions.

Fig. 3 - School of Paul Brill (attributed), The Castle and the Guevara tower of Bovino, first quarter of the 17th century [Delizia, 1987]

Fig. 4 - B. Tortelli, The islet with the Castle of Ischia,1576-1586 [National Library of Naples, Manuscripts and Rare Section, Ms. XII.D.1 c. 12r]. In the red box is identified the stretch of fortification subject to analysis

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THE METHODOLOGY APPROACH

The aim of this research is to create a workflow that, through the use of digital tools and scientifically controlled input data, leads to the semi-automatic identification of the most degraded surfaces that require more urgent interventions, in order to ensure correct technical and economic planning. In this workflow, the digitization phase of all the artifacts present inside the fortified citadel was of fundamental importance to have a greater control of the state of conservation of the material.
For this reason, the first step of the workflow (Fig. 5) concerned the digital survey of architectural and engineering emergencies of interest. At the moment, the digital survey and the graphic elaboration have concerned the Cathedral of the Assumption, the crypt of Saint Peter, the Church of the Immaculate, the Cemetery of the Nuns, the Piazza d'Armi, many parts of the fortifications, the Aragonese bridge, the access tunnel, and many of the island's pedestrian paths.
The digitization of the artifacts was done through integrated survey procedures with terrestrial laser scanning and aerial and terrestrial photogrammetry. Focusing on the individual case study of the fortifications around the Piazza d'Armi, laser scanning was used to survey the square, access paths and part of the retaining walls and to obtain reliable ground control points for the photomodelling phases. Aerial photogrammetry, instead, was used to survey the vertical fortifications overhanging the rock, the crests of the walls and the chromatic aspects of the surfaces: elements difficult to acquire through terrestrial laser scanning due to the inaccessibility of the objects and the quality of the chromatic data required.
Thirty-eight laser stations (with Leica BLK360) were required for the survey. The cloud alignment phase took place quite easily (in Autodesk ReCap environment) thanks to overlapping surfaces abundant between single points cloud that have ensured an excellent solidity of the final model, which counts over 300 million points (Fig. 6).
Regarding the aerial photogrammetric survey, three flights were planned by APR (DJI Mavic 2 pro) setting the camera with vertical and inclined axis to 45, and 5 flights were conducted in VLOS mode with almost horizontal camera axis (Fig. 7).

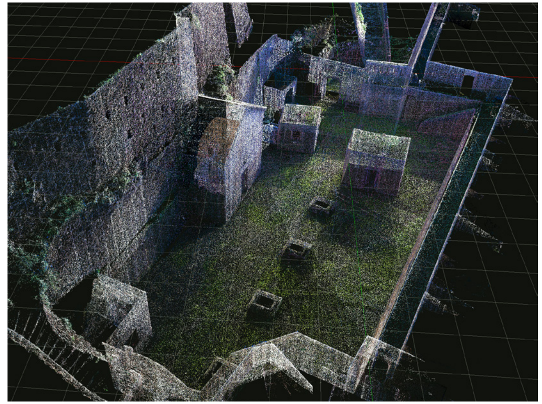

Fig. 6 - Laser-scanning points cloud model

Fig. 5 - Workflow

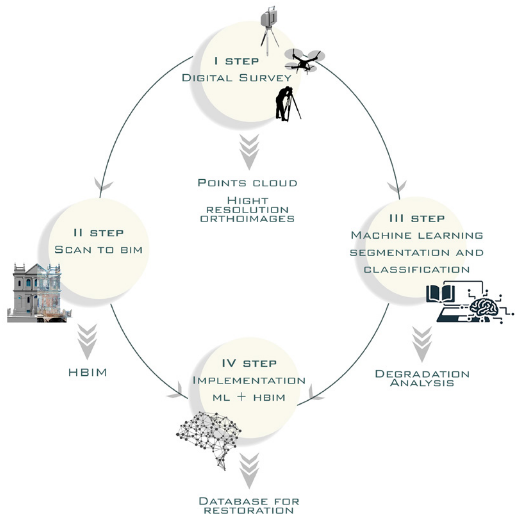

Fig. 7 - UAV flying projects around the Piazza d'Armi

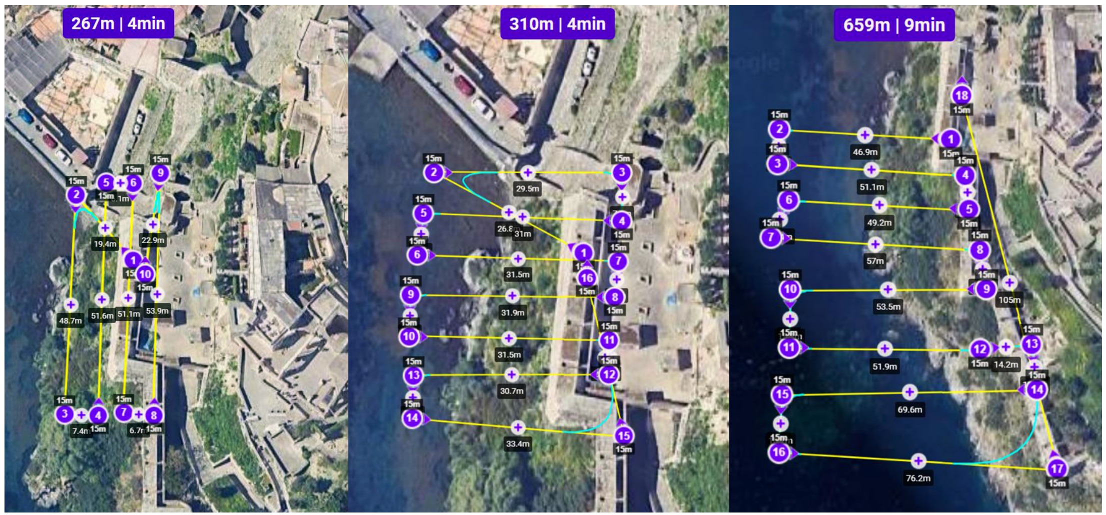

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Fig. 8 - Image-based points cloud model

Under these conditions, about 600 photographs were taken at maximum resolution.
The photomodelling phase (conducted in the Agisoft Metashape environment) has exploited the coordinates of five points of the cloud by laser scanner, used in effect as GCPs. The image-based model, formally controlled, has over 60 million points (Fig. 8).
With this model have been realized orthoimages to very high resolution of the surfaces of the fortifications (the minimum GSD obtained was equal to about 4 mm/pix) that have been used in the successive steps of Machine Learinng for the recognition of the degradation (Fig. 9).
In order to create a model without gaps of information, the two clouds were aligned in a single model (in the CloudCompare environment).
The second step of the workflow concerned the parametric modeling of Piazza d'Armi through scan-to-BIM procedures in Autodesk environment. The critical issues related to the modeling of unconventional geometries belonging to ancient buildings have been overcome thanks to parametric modeling implemented in Revit platform, exploiting the potential of geometric customization of solid instances through the use of local families. Once the level of accuracy to be achieved has been defined, the local families have been mainly employed for the modelling of the walls (with variable section along their development) and of staircases (Fig. 10). The H-BIM model obtained for this case study does not intentionally take into account the technological aspects related to building materials since, as will be seen soon, the aim was to enrich it with information on the state of degradation of external surfaces.
The third step, contextual to the previous, concerned the segmentation and semi-automatic classification of some more recurring factors of surface degradation through the use of high resolution orthoimages. The process made use of the Trimble eCognition Developer software through several steps:
a) choice and setting of the segmentation algorithm;
b) control of the results;

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Fig. 9 - Ultra-high resolution orthoimage of fortifications around the Piazza d'Armi

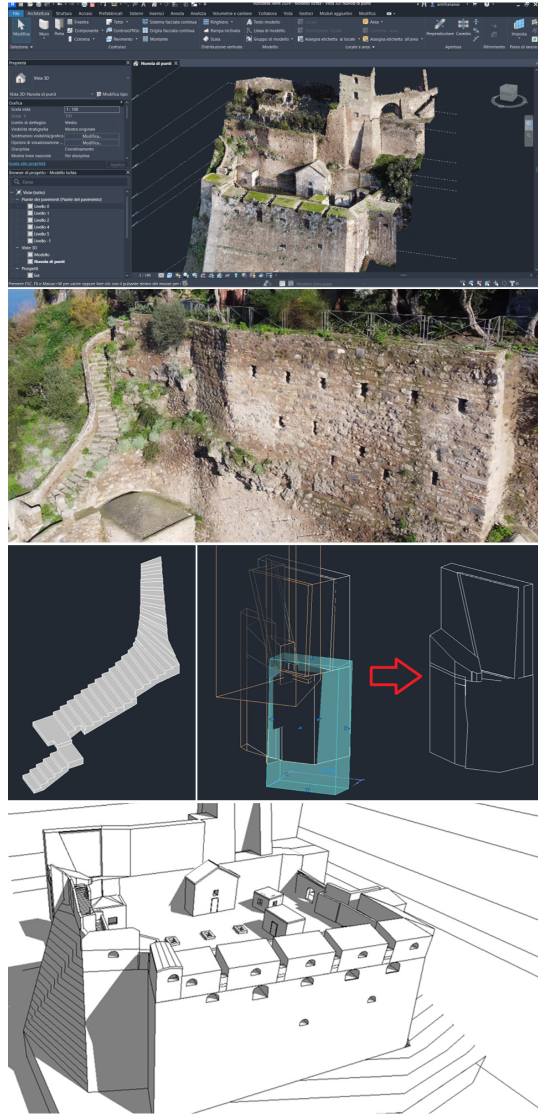

Fig. 10 - From top: definition of the levels preparatory to the scan-to-BIM procedures; a portion of wall and steps with complex geometries; some elements modeled with local families; H-BIM of Piazza d'Armi and fortifications

c) definition of the classes to be used;
d) training of the classification algorithm;
e) control of results;
f) classification.

For the case study, some zones visibly affected by degradation were identified, of which parts of orthoimages were identified, then imported into the software in compressed .jpg format. For the research objectives, the "multiresolution segmentation" algorithm was chosen, appropriately set in the parameters "scale", "shape" and "compactness" according to the quality of the images to be examined. The result of the segmentation returns appropriately vector images depending on the setting of the starting algorithm.

For the classification operations, classes have been defined, corresponding to the most common and widespread degradation factors on the fortifications: lack of plaster, joint erosions, infesting vegetation, as well as shady areas. The training of the classification algorithm took place by manually identifying 4 or 5 degradation regions for each class. The obtained classifications have returned acceptable results for the level of study required by an analysis of degradation aimed at the design of surface restoration interventions. The raster images of the analyzed surfaces already in themselves represent an infographic output of considerable technical-scientific value (Fig. 11).

The last step concerned the informatization/implementation of the H-BIM model with raster data obtained from ML processes. The goal was to apply the degradation textures to the relative parametric surfaces (Fig. 12). In order to associate the automatic zoning of the surface degradation to the relative geometric instances the informative archiving through linking of the obtained patterns in the phase of recognition has been chosen. In the first instance, the content of the images has been used as an information base that does not directly define a stand of the geometric instance in parametric terms but represents a useful piece of information outside BIM-oriented assessments, so as to use this information as a database element for technical assessments. At the same time, through georeferencing processes, raster grids and their information content were integrated directly on the reference vector surface. In this

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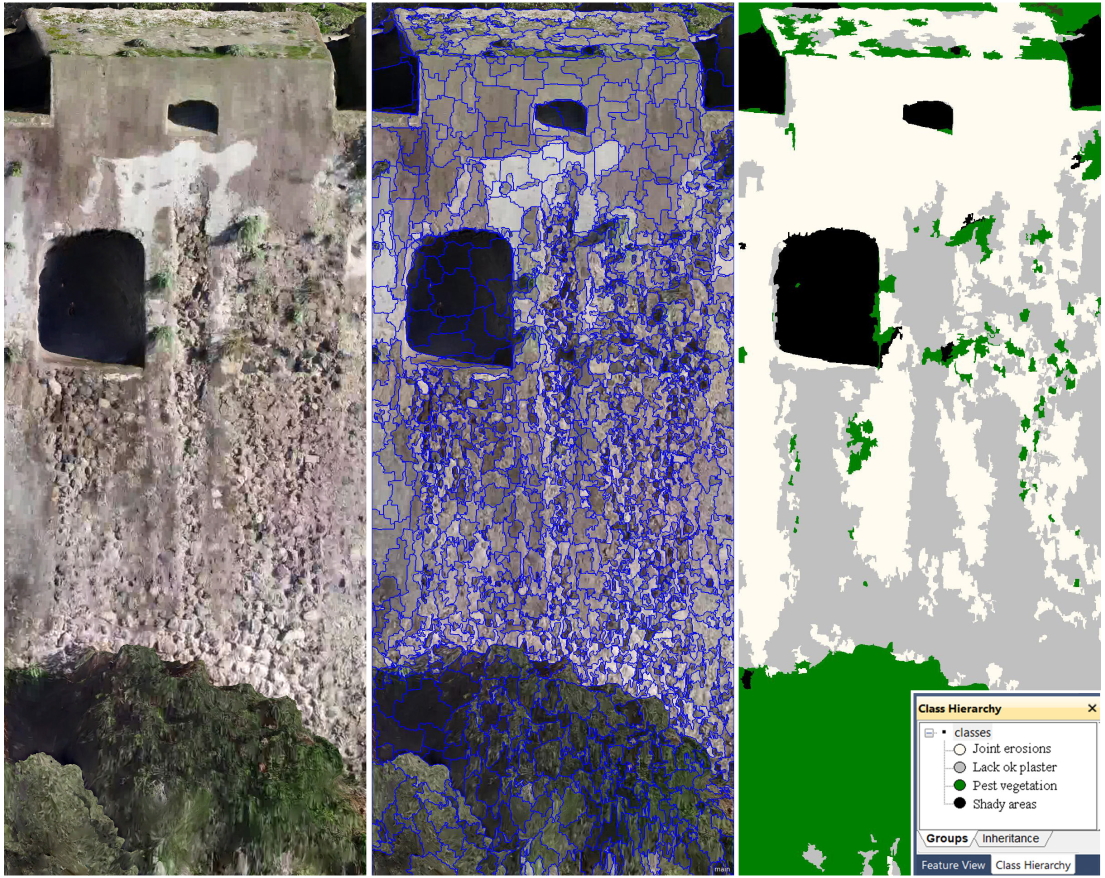


Fig. 11 - Degradation analysis through ML procedures. From left: part of the ultra-high resolution orthoimage; segmentation; degradation classification

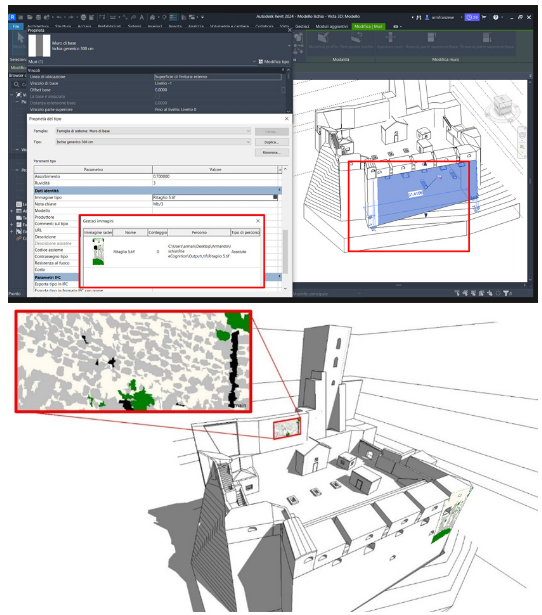
way, the completed operation intends to represent a texturization procedure, in which the degraded information can be located directly on the parametric model.

RESULTS AND CONCLUSIONS

The described procedure represents an ongoing research to refine and synthesize. On the one hand the degradation zoning is geolocalizable directly on the geometric reference instance, on the other hand the information transfer is not yet directly acquired in a pixel-to-point logic: the grid value of the pixel of the associated raster grid cannot be associated with the vector point to which it refers. This is the reason why, in this paper, the intrinsic reading of the data has been preferred for the direct use of the BIM parametric model.

The possibility of pyramidal generation of information, by direct action from grid raster to geometric instance BIM, would lead to the definitive consideration of similar parametric models as containers of varied and differentiated information that can be useful for different application domains: we are still in an evolutionary phase of HBIM for which, for example, operators of restoration and maintenance still find it difficult to fully use these parametric technologies to translate the phases of analysis and design into data engineering.
If this were to happen - and this research is intended to contribute to this – it would result in the creation of a digital cultural heritage as a set of «unique resources in the fields of knowledge and human expression, whether cultural, educational, scientific, administrative or containing technical, legal, medical or other information...» [Carta sulla conservazione ..., 2003].

Fig. 12 - Integration of data segmentation and scan-to-BIM



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