Archaeo-BIM: Considerations for a Semantic Tree for the Built Heritage of Pompeii

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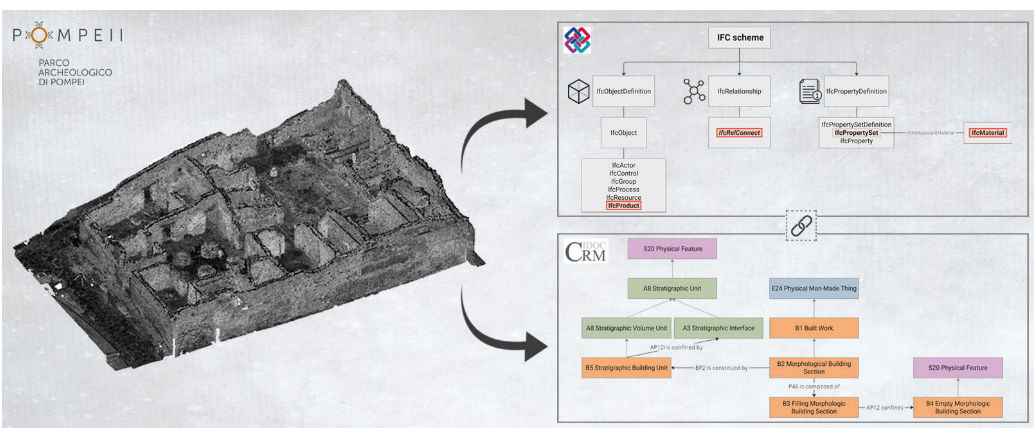
Abstract

Informative systematisation is a crucial issue in the management of Archaeological Heritage. In an area of considerable historical relevance such as the Vesuvian one, the integration of BIM (Building Information System) and GIS (Geographic Information System) systems sets a contemporary challenge while providing new opportunities for site valorisation and administration. The paper focuses on BIM methodology, exploring how its ability to model complex structures on a geometric and informational level can deliver a comprehensive view also in the domain of archaeology. The study develops from the semantics of the archaeological domain between the republican and high imperial age analysed in parallel with the semantics adopted by the IFC (Industry Foundation Classes) scheme, for the communication of information according to a standardised workflow for digital modelling. The analysis of these two languages allows to understand to how closely archaeological ontologies can collimate with semantic relations in the BIM environment, highlighting criticalities and potentialities of integrating entity, conceptual and structural information in a unified model. A focus is on the ontology model CIDOC CRM (Conceptual Reference Model), to facilitate the understanding of data where gaps exist between archaeology and IFC to be implemented or improved. Its use is explored as a basis for the creation of specific ontologies for the Vesuvian domain, to guarantee a coherent representation of historical and constructive data and defining a normalised method to guarantee the preservation of archaeological assets.

Keywords
Archaeo-BIM, CIDOC CRM, IFC, semantics, Pompeii.



Exemplification of the workflow for a semantic dialogue between IFC and CIDOC CRM (image by G. Angrisani).

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Introduction

By the specificities and the amount of information that has emerged to date in the archaeological field, which is constantly being updated and enriches the historical and cultural heritage, research groups and site management, protection and promotion institutions increasingly need to expand and enhance their archives. At the same time, there is also a need to develop new ways of acquiring and cataloguing this information, constantly adapting to technological and methodological advances in the sector. This is the context for the research project 'BIG_SMAART - BIM & GIS for Spatial and Muldidimensional Archaeological Artefacts and Techniques', a study funded by the PRIN programme 2022 of the MUR [1]. The project aims to structure a response to the need for systematisation of the corpus of information and documentation for archaeological contexts, restricting its analysis to the case study of the Vesuvian context. To this end, the research is based on an accurate study of GIS - Geographic Information System and BIM - Building Information Modeling, attempting to provide a solution to archaeological needs by defining a criterion of interoperability between these two languages, traditionally used in the field of archaeology, the first, and in the architectural sector, the second. Several studies appear in the literature concerning the dialogue between the archaeological and BIM (Archaeo-BIM) domains, and it is well known that GIS has been a very valuable tool for archaeology and site management for years. However, both theoretical and applicative examples of interoperability between BIM and GIS systems for the ancient built environment are extremely limited [Gaffney, Van Oosterom 2005; Shih, Wu 2015; Colucci *et al.* 2020; Carpentiero 202; Rechichi 2021]. Starting from the semantic decomposition and description of the archaeological object in relation to the surrounding context, the aim of the project is to define an integrated and standardised methodological flow that allows archaeological data to be documented and updated in the form of uniquely recognised entity libraries in both GIS and BIM systems [2]. To achieve this goal, the starting point of the research is the study of how the current data schemas constituting GIS and BIM systems meet the needs of digitising and cataloguing Vesuvian architecture, as well as defining how these data management models can be integrated and interact in a purely archaeological context [Bosco *et al.* 2024]. Given that the project is based on the analytical parallelism of the two systems, this article will discuss in more detail the BIM component and its relationship with archaeology, what the potential is for a semantic correspondence between the two domains, where the most obvious gaps are, and how they can be bridged by using a third conceptual reference model that allows the inclusion of other ontologies to label entities and relationships..

Challenges of Archaeo-BIM: reflections and methodological approach for the Vesuvian context

The archaeological sites in the Vesuvian area (Pompeii, Herculaneum, Stabiae) are characterised by an extraordinary variety and uniqueness, features that make them among the most significant in the world. The uniqueness of these sites lies not only in the variety of structures, ranging from private residences to public buildings, but also in the incredible state of preservation, which allows us to relive aspects of Roman society like few other places in the world. To define a strongly applied methodological approach, the BIG_SMAART project chose to work in the context of the Archaeological Park of Pompeii, an exemplary case of Roman architecture dating from the period between the Republican and High Imperial age that offers scholars a crystallised image of the life, customs and habits of an active and prosperous civilisation that developed on the slopes of Vesuvius. In the remains of private buildings and public spaces resides an ancient memory, recounted to us by the interpretation that experts give to the archaeological artefact based on a critical analysis of the data found. It is precisely for an understanding as close to reality as possible that a correct and scrupulous cataloguing and reading of the artefact becomes fundamental. In fact, these memories, in addition to being tangible, are today already collected in a vast archive that the Archaeological Park of Pompeii has created as part of the Great Pompeii Project, called the

Plan of Knowledge [De Caro, Mazzoleni 2015]. It is a corpus that brings together material, formal, and compositional information from on-site surveys, studies, and archival sources, aimed at the optimal management of the site (fig. 1).
However, the Park's need to define a database that is recognised, readable and sharable at an international level, and not only among the players operating in the Pompeian context, means that BIG_SMAART can find opportunities for research. For the definition of a method, however, it was necessary to examine a sample illustrative of the complexity of the Pompeian context, such as Building VIII 6.1/8-11, also known as the 'Bakery House' (figs. 2, 3).

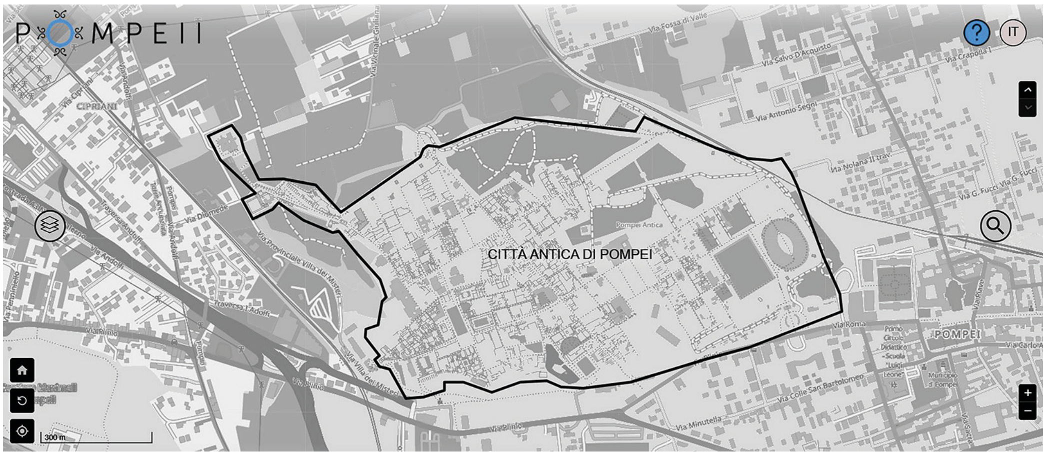

Fig. 1 Fig. 1 'Great Pompeii' Project, Plan of the ancient city of Pompeii (image from https://open.pompeiisites.org/, edited by G. Angrisani)."

Development of a semantic dialogue between IFC and CIDOC CRM ontology for Archaeo-BIM

To create an information model that would allow the elements of the archaeological domain, their attributes and relationships, to be related to the BIM model, the first step was to study the objects of the Roman built environment typical of the republican and high imperial age, through a census conducted in situ with the support of archival and bibliographic sources. This analysis conducted for the Archaeological Park of Pompeii saw of central importance the study in semantic key of the archaeological evidence typical of the site to elaborate a formal tree in which each element is represented in identity, structural and qualitative terms. The analysis of the elements was first conducted on the archaeological inventory of

Fig. 2 'Great Pompeii' Project, Plan of the knowledge. Plan of Building VIII 6.1/8-11 (image from https://open.pompeiisites.org/, edited by G. Angrisani).

Fig. 3. Fig. 3 *Great Pompeii* Project, Plan of the knowledge. Point cloud of Building VIII 6.1/8-11: detail of the millstones (image by G. Angrisani, from point cloud acquired by L'Orientale).

the entire Vesuvian area, with particular attention to the Pompeian site, and then on the evidence of the case study. According to the criterion adopted, the archaeological objects were classified according to three macrocategories, corresponding to the disciplines of the *Revit* authoring software and the categorisation assigned by the BIM validation and control software: architectural, structural and MEP disciplines (Mechanical, Electrical, and Plumbing)..
The elements having common characteristics of morphology and function were grouped to create sets and subsets, always considering those of construction technique and materials as formal parameters of the object. Each of the colour-distinct sets (8 structural in green, 9 architectural in orange and 7 plant engineering in blue) was declined into a certain number of subsets, and consequently a given number of elements for a total of 368 entities (fig. 4). These archaeological entities were also defined from a relational point of view, considering the meronymic and topological relationships between them.
Having developed the semantic analysis from an archaeological point of view, the same procedure was carried out by attempting to translate the same entities and their respective relationships into IFC language, to understand whether and how the two structures could correspond. The archaeological semantic model just described was compared, therefore, to the IFC relational logic based on Family, Type and Parameters: these concepts were respectively compared with those of sets of common elements, construction technique (subsets) and materials used. Thus, for example, the 'wall' set of the archaeological domain was associated with the IFC family class 'IfcWall', the construction technique was associated with the Type 'IfcType', while the material parameters were related to the materials defined in the BIM environment with the basic material definition instance 'IfcMaterial'.
The method was supported by an analytical study of the IFC schema, as an information model that encodes entities according to semantics, attributes and relationships, guaranteeing interoperability between file formats in the BIM environment [Eastman *et al.* 2011]. In it the elements are developed into two structures: a hierarchical-enumerative classification and an analytical-synthetic one.
The first (fig. 5.) is a rigid, vertical structure where all categories are linked to each other through hierarchical subsets, defining a scalar path from the generating element to more specific ones. In this logic, each element assumes a specific position in relation to its predecessor

Start	End	Label	Label 1	End 1	Label 2	End 2	Label 3	End 3	Label 4	End 4	Label 5	End 5	Label 6	End 6	Label 7	End 7		
Wall																		
Wall	Opera incerta	Built with																
Opera incerta	Limestone	Made by	and	Lava	and	Cruma												
Opera incerta	Limestone	Made by																
Opera incerta	Lava	Made by																
Opera incerta	Limestone	Made by	and	Lava	and	Cruma	and	brickappeals										
Opera incerta	Limestone	Made by	and	Lava	and	Cruma	and	grey tuff	and	reuse elements								
Muro	Opera mista	Built with																
Opera mista	Brickworks	Made by	and	grey tuff	and	yellow tuff												
Muro	Opera vittata mista	Built with																
Opera vittata mista	Brickworks	Made by	and	limestone														
Muro	Window opening	In relation with	and	Door opening	and	arch	and	balcony	e	kitchen counter	and	store counter	and	cantonment	and	column		
Infill																		
Infill	Opera incerta	Built with																
Opera incerta	Limestone	Made by																
Opera incerta	Lava	Made by																
Opera incerta	Cruma	Made by	and	Limestone	and	lava												
Opera incerta	Lava	Made by	and	Limestone	and	Reuse elements												
Opera incerta	Limestone	Made by	and	Brickworks														
Opera incerta	Lava	Made by	and	Brickworks														
Infill	*Opus testaceum*	Built with																
Opus testaceum	Mattoni	Made by																
Infill	Wall	In relation with	and	window opening	and	door opening	and	arch	and	lintel	and	wall cladding-preparation	and	wall cladding-decoration	and	wall calddinf-frame	and	theshold
Duct	Exhaust duct	Functioning as																
Exhaust duct	Channel	Type																
Channel	Masonry	Made by	and	Brickworks														
Channel	Brickworks	Made by																
Channel	Grey tuff	Made by																
Exhaust duct	Descent duct	Type																
Descent duct	Leaning to wall	Made as																
Descent duct leaning to wall	*tubuli*	Made by																
Tubuli	terracotta	Made by																
Descent duct leaning to wall	*fistula*	Made by																
Fistula	Lean	Made by																
Duct	wall	In relation with	and	tank	and	column	and	Floor covering	and	vera	and	theshold	and	oven				

Fig. 4. Detail of semantic scomposition by disciplines (image by G. Angrisani).

or successor. The second structure (fig. 6.) favours, on the other hand, a more flexible logic with a purely horizontal development, in which each object is simultaneously considered to have several overlapping characteristics at the same level with each other. Through this logic, which is no longer hierarchical, these characteristics are potentially more and more implementable and aggregable with each other.

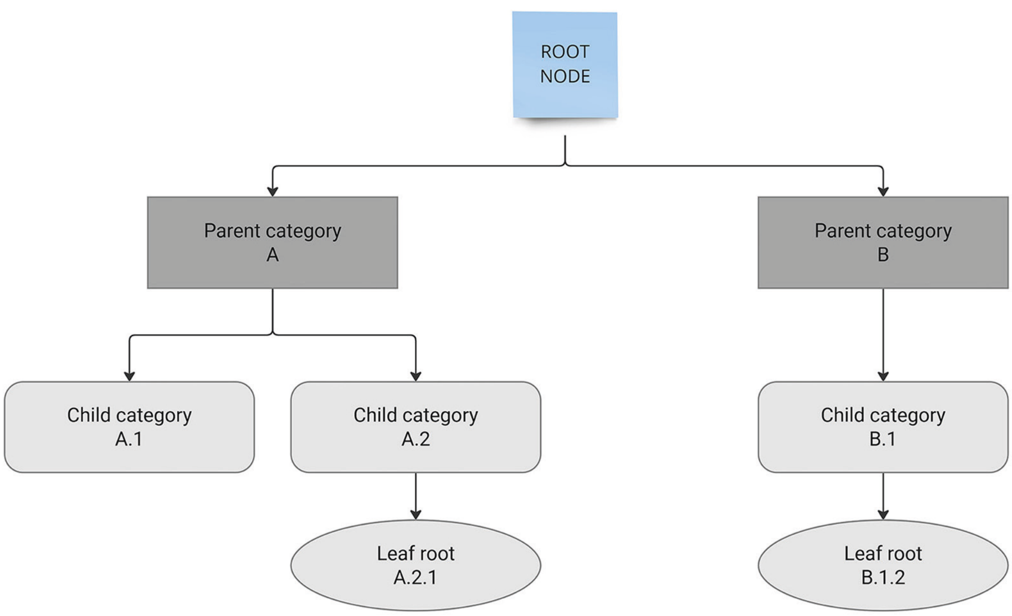

Fig. 5. Example of a hierarchical-enumerative tree scheme (image by G. Angrisani).

Starting from this consideration, the archaeological entity 'Wall' made of mixed masonry and limestone was taken as an example. It can be seen in figure 7 how the IFC hierarchical - enumerative classification develops vertically starting from the matrix entity 'IfcRoot', from which a series of other abstract entities decline until the definition of 'IfcWall' which, as already mentioned, is assimilable to the family class 'Wall'. The subset 'mixed-wall construction technique' of the archaeological domain has been associated with the entity 'IfcWallType', which defines common information more specific to a particular construction element. The analytical-synthetic classification, on the other hand, is deduced from the horizontal development of the masonry and limestone materials that have been related to the 'IfcMaterial' instance, which, not being subject to particular constraints, can potentially be extended to more materials than those considered. The 'IfcRelAssociateMaterial' relation describes a direct assignment of isotropic or anisotropic material characteristics to the object. Finally, as an example of an object-object relationship, the entity 'IfcDoor' was chosen to be related to the host entity 'IfcWall'. This is done in IFC language via the abstract connectivity relation 'IfcRelConnect'. Contextually, the semantic tree for archaeological buildings was related to the classes and properties encoded in the CIDOC CRMba ontology, an extension of CIDOC CRM (Conceptual Reference Model) to support buildings archaeology documentation [Ren, Di Giovanni 2019]. This work was carried out where it was found that not all entities and relationships typical of the archaeological domain can be accurately associated with the IFC relational schema.
A glaring example of the lack of correspondence between the archaeological domain and the IFC language is that of the instance 'well' which, to date, is not present in the semantics of standardised IFC entities, and for which it is therefore not possible to proceed with the same reasoning adopted for the element 'wall'.
The use of association with a more general and extended ontology for the domain of interest makes it possible to exploit ontological labels to create links and semantic inferences that cannot be directly associated between the two contexts.
For this reason, the CIDOC CRM schema has been adopted, which is extensively employed and internationally recognised with its extension created specifically for the context of archaeology [Crofts, Doerr 2010].
In particular, for the domain under examination, the labels of classes 'B1 Built Work', 'B2 Morphologic Building Section', 'B3 Filled Morphologic Building Section', 'B4 Empty Morphological Building Section' and 'B5 Stratigraphic Building Unit' were associated with the various archaeological entities, connected, through properties of the type 'P45 consist of (is incorporated in)' and 'P33 used specific technique (was used by)' , considering instances of 'E18 Physical Thing', 'E24 Physical Man-Made thing', to classes 'E57 Materials', 'E29 Design or Procedure'.

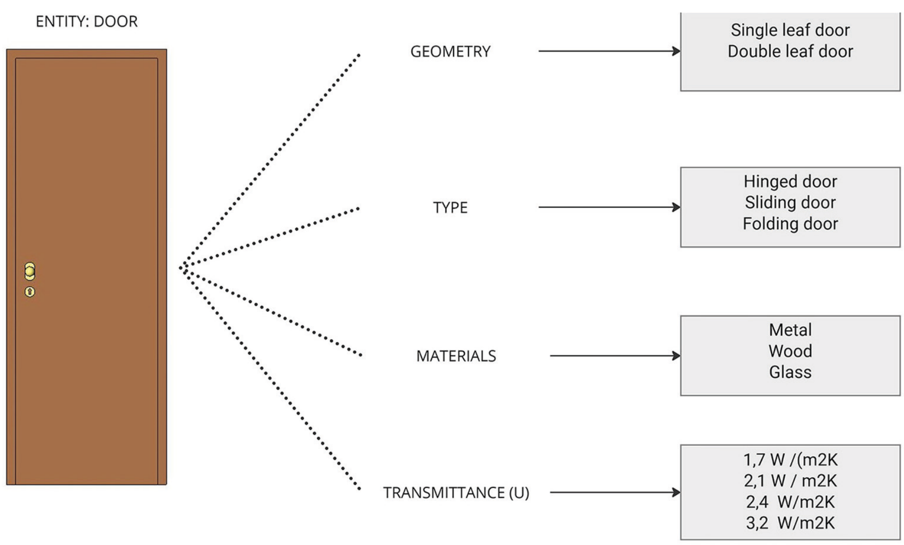

Fig. 6. Example of analytical-synthetic classification (image by G. Angrisani).

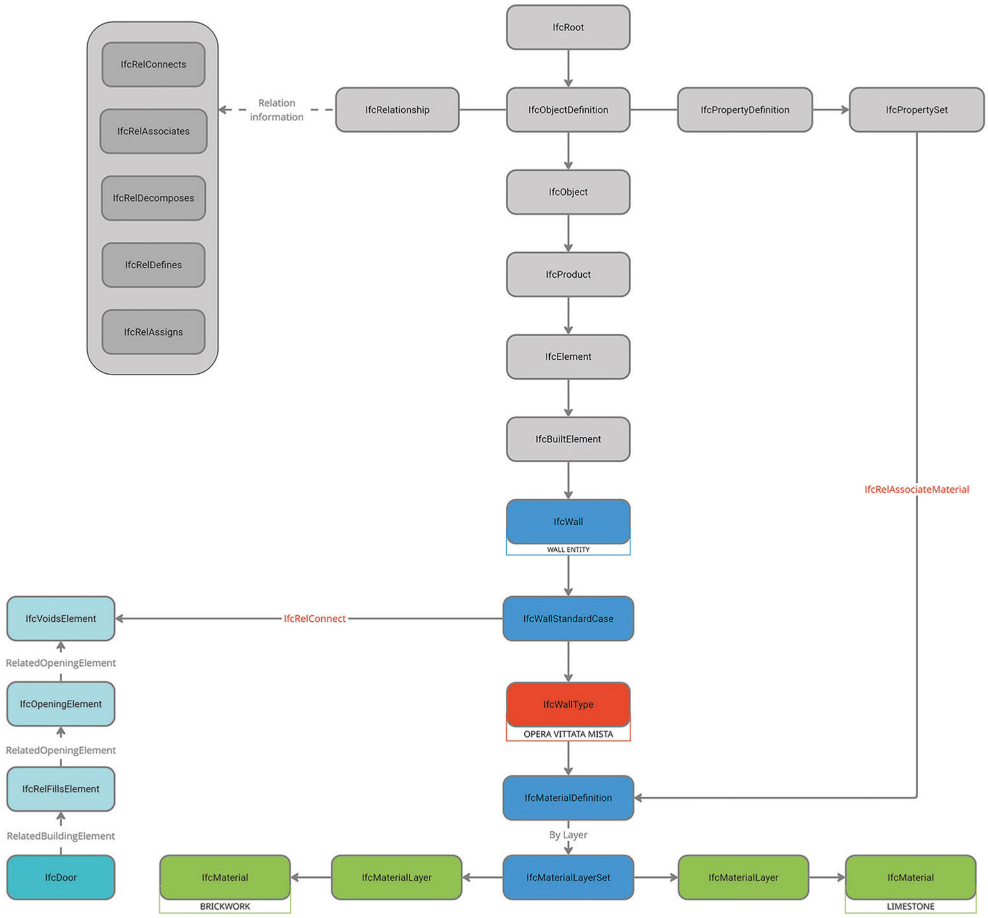

Fig. 7. Example of semantic dialogue of an archaeological 'wall' entity with IFC language (image by G. Angrisani).

Conclusions

The adoption of BIM, and its integration into GIS, in archaeological practices is opening up new opportunities for the management and protection of cultural heritage. Projects such as BIG_SMAART are geared towards demonstrating how these technologies can improve the documentation, management and fruition of the archaeological heritage, enabling its accurate representation and constant monitoring of information and conservation conditions. To date, the use of the IFC model in archaeology opens the way for an interdisciplinary approach combining architecture, archaeology and digital sciences, improving accessibility and collaboration between the various actors involved in heritage conservation. Evident limitations still exist, however, in the semantic representation of archaeological objects and in the possibility of defining them coherently within the framework of relationships connecting them to other elements of the specific domain. The adoption of advanced semantic models, such as CIDOC CRM, and the use of archaeology-specific ontologies, allows for a better integration of data from different sources, favouring the creation of a shared knowledge base. However, although the potential is clear, the way towards large-scale adoption of these technologies requires continuous development and standardisation, as well as the training of professionals capable of managing and applying these tools effectively. In the future, the synergy between BIM, GIS and ontological models can play a crucial role in ensuring the protection and enhancement of cultural heritage, allowing future generations to better enjoy and understand our past.

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Notes

[1] The project members are: A. Bosco (P.I.), G. Borriello, A. D'Andrea, D. D'Auria, F. Forte (University of Naples L'Orientale); V. Cera (Sub P.I.), G. Angrisani, G. Barile, M. Camerino, M. Campi, M. Capone, A. Cicala, A. di Luggo, M. Falcone, F. Itri, A. Lo Pilato, A. Pagliano, D. Palomba, L.S. Pappalardo, S. Scandurra (University of Naples Federico II); L. Fregonese (Unit Manager), O. Rosignoli (Politecnico di Milano).

[2] Although this contribution is the result of a shared work, G. Angrisani is the author of paragraphs 1 and 2, V. Cera is co-author of paragraph 2, introduction and conclusions are by all authors.

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