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Original article

The architecture of warehouses: A multidisciplinary study on thermal performances of Portus' roman store buildings

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ABSTRACT

In the framework of the French Research Agency program "Entrepôts et lieux de stockage dans le monde gréco-romain antique", a multidisciplinary study on the archaeological, historical, constructive and architectural characteristics of Ostia and Portus' warehouses is ongoing. The final aim of the project is to understand the role these warehouses played in the process of storage and distribution of food supplies. The starting point is the study of the degree of knowledge the ancient people had in storage techniques. Numerical predictive computational models, supported by in situ measurements to characterize dimension, geometry and materials, are in this paper considered as essential "tools" for the historical, archaeological and functional interpretation of the roman store buildings. In this paper, different hypotheses of the architecture of Portus' store buildings are analysed and compared using computer fluid-dynamic models in order to support archaeologists in their effort to better understand how ancient warehouses were built, managed and used.

1. Research aims

In the field of archaeology, it is easy to run into studies and cases that cannot always be interpreted. Some examples might be represented by destroyed sites where remains do not allow for the reconstruction of the original building or by the lack of consistent information about systems and methods used in ancient times. Historical and architectural evidences sometimes allow making assumptions that may not be fully confirmed. A good way to supply other information and evidences could be coupling archaeological and numerical analysis.

A good example in this way is represented by Ostia's and Portus' warehouses, focused in this paper, in which a scientific collaboration between IRAA (Institut de recherche sur l'architecture antique of CNRS) and DIAEE (Department of astronautical, electrical and energetic engineering of "Sapienza" University of Rome) developed an approach based on CFD simulations to overcome some limits in the archaeological reconstruction of the volumetric architectural design of destroyed structures in Portus.

2. Introduction

Ostia's and Portus' warehouses were important elements in the hub for trade between Rome and its provinces [1,2]. Archaeological studies have often left unsolved many questions related to storage systems, because what remains does not always allow the entire reconstruction of the original structure [3,4].

Predictive computational models are one of the latest applications in the world of cultural heritage. They analyse and represent the physical environment through the numerical/geometrical resolution of complex mathematical equations, which govern the thermo fluid dynamics and the visual and the acoustic phenomena.

At today, predictive numerical methods are not only intended and used for architectural/engineering solutions related to the conservation of cultural heritage (covering, microclimate, lighting, ventilation), they but can also represent an essential "tool" for the historical and archaeological interpretation of ancient structures [5–8].

Nowadays, the archaeological data and evidences can be used in a hermeneutic approach, in which different hypotheses can be analysed to reconstruct the past, using a virtual model inside an iterative process driven by archaeologists. This hermeneutic approach partially erases the sense of extraneousness in computer simulations that had characterized the early stage of numerical applications. This last approach, as example, can be found in Chourmouziadou and Kang [9], Gugliermetti et al. [10] for the acoustic

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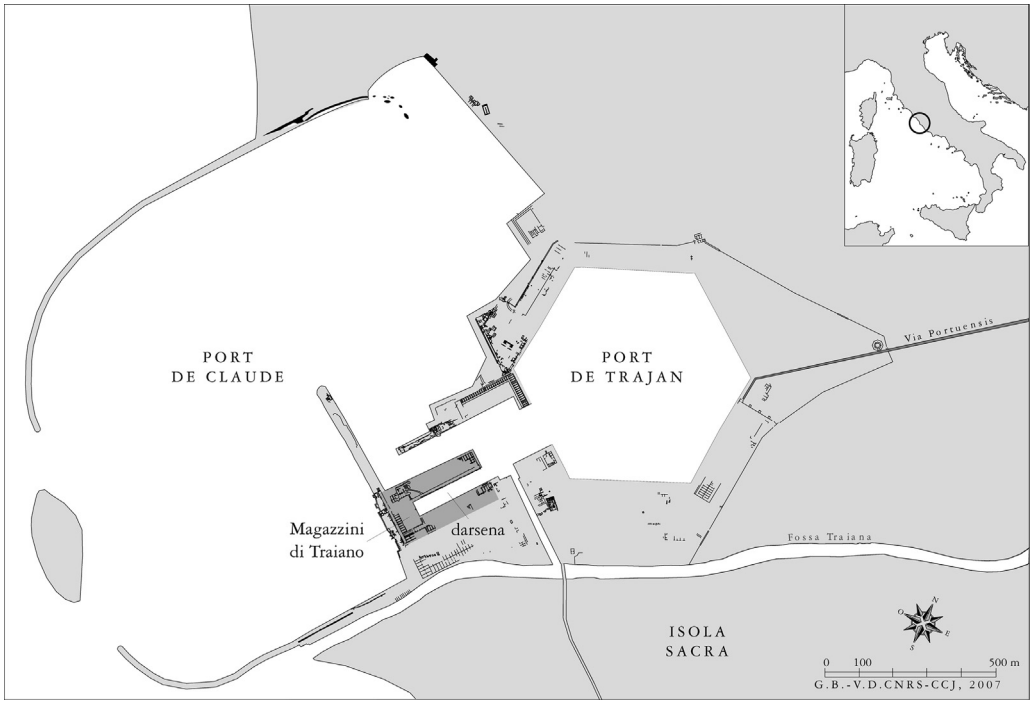

Fig. 1. Topographic inclusion of Traian warehouses of Portus in the port system [18] (Fig. 91).

environment referred to ancient theatres, or in Navvab et al. [11] for the visual and luminous aspects of museum.

Most of the authors used CFD simulation to study and analyse indoor environments, mainly to define the best conservation and preservation conditions for cultural objects, while there are not many studies devoted to support directly the archaeologists' work. For example, Albero et al. [12] simulated the virtual microclimate conditions in the Hall with the gilded vault in the "Domus Aurea", while Balocco [13] considered the interaction between indoor and outdoor microclimatic conditions and the thermophysical behaviour of the Hall of the two hundred in the Old Palace of Florence. Besides Oetelaar et al. studied [14] temperature distributions in a Roman bath, and Hussein [15] and Hussein and Shishiny [16] investigated the low-speed wind environment around the Great Sphinx. Finally, Gan [17] considered interaction between external and internal airflow through a complex historical building.

This paper presents a reconstruction of Portus' storage buildings based on a multidisciplinary approach in which different hypothesis of warehouses', architectural aspects and materials, developed by archaeologists, are analysed by computational fluid dynamics (CFD) models in order to determine the resulting compatibility between indoor microclimatic conditions, linked to the considered architectural reconstruction, and storage requirements. The paper represents a first step to the knowledge of the ancient conservation techniques. It is oriented to solve one of the main concerns archaeologists have in this study, that is to demonstrate the existence of external openings. In this way, it has been demonstrated how the numerical analysis can give a fundamental contribution in the validation and the proposition of archaeological reconstruction hypothesis.

3. Topography of the site

The Traian warehouses in Portus are characterized by their interconnection with the harbour system [18]. The entire historical structure is enclosed by open sea on the West side and by a system of canals and docks on North and East sides (Fig. 1). This topographic position influenced the transport and the storage of goods.

Maintaining a certain symmetry, the Traian warehouses present a "U" shape around the dock opening at East, in the direction of the hexagonal basin of the port of Traian. The rectangular block, consisting of three buildings and a central basin, is about 315 m long by 175 m wide. The first archaeological investigation put in evidence the existence of about 150 storage cells on the ground floor. The presence of many traces of stairs definitely testifies the existence of another level of storage that would double this number to obtain a total of 300 independent warehouses.

Considering only the ground floor, the surface area useful for the storage arrived at about 12.150 m^2, more than one hectare. The entrance of the cells was always oriented to the external street for goods transportation [19] (Fig. 2).

4. Archaeological and historical approach: geometry and structure of the cells

The geometry of the cells (Fig. 3) is generally the same, but often some details change from one cell to another, such as the arrangement of the air gap. Virtual reconstruction of Cell F.47 (Fig. 4), realized basing on in situ measures and archaeological considerations, has been taken as an example for the architectural reconstruction of the model. It is located on the West side of the warehouses and looks out into the Portico of Claudio.

The Cell F.47 measures approximately 14 m (length) by 6.30 m (depth). The covering is composed by a stone barrel vault and the maximum high of the cell is about 8.5 m (from the floor up to the keystone). In analogy with other Roman storage cells, it is possible to suppose that this lengthened structure is typical of all the storage cells of Ostia and Portus' warehouses.

The travertine threshold was raised by about 30 cm from the external ground-level and the pins were arranged to allow the doors opening towards the outside, thus, facilitating the maintenance of goods. At the end, a device consisting of two pillars of about 60 cm width completed this locking system. The pillars extended

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