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Original article

The contribution of numerical simulation for the diagnosis of the conservation of art objects: Application to Antonio Santucci's armillary sphere of the 16th century

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Abstract

Antonio Santucci's armillary sphere is one of the symbols of the wealth of the world cultural heritage: it is an elaborate representation of the geocentric universe as it was known at that time. Its exceptional dimensions (more than 3 meters high) make it an object which is considered as a complex structure, built with a technique of mixite made of nail-laminated timber. Constructed at the end of the 16th century, this sphere has suffered wear and tear, mostly due to the combined effects of gravity loads over time and environmental agents (such as variations in the relative humidity of the air), as well as means of exposure of the object.

The purpose of this research project is to study delayed phenomena, and it lies in the evaluation of the coupled mechano-sorptive effects likely to generate a critical state which would threaten the stability and the durability of the structure. This study highlights a problem which is already very real, even though irreversible consequences may not appear until the future. This work shows the importance of taking into account the variations in relative humidity undergone by the environment in which the sphere is exposed. These changes are at the origin of increasing deformations which could soon become prejudicial to the satisfactory conservation of the object.

Keywords: Conservation; Wood material; Nail-laminated timber; Relative humidity of the air; Mechano-sorption; Creep; Numerical tool; Finite elements modelling; Astronomy

1. Introduction and purpose of the research

The armillary sphere, designed by the cosmographer Antonio Santucci de Pomarance at the end of the 16th century and stored in the History of Science museum in Florence, is one of the symbols of the wealth of the world cultural heritage: it is an elaborate representation of the geocentric universe as it was known at the time. This art object, which is unique, bears witness to sixteen centuries of scientific thought, of which Ptolemy was one of the most famous precursors. Hence, under no circumstances must its value be neglected or forgotten.

The armillary sphere was created to represent more clearly apparent celestial movements and their resulting phenomena. Nine spherical surfaces are represented by outlying rings: one motionless (the firmament) and eight others animated (the first mobile and the planets), with the Earth at their common centre. To make it stand out better, the Earth is proportionally much larger than the distances between it and the outlying rings. An associated axis, which goes through its

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centre and its poles, holds up most of the components and allows the rotation of the movable internal spheres by means of a simple mechanism [1].

Immediately one tries to understand these testimonies to history and culture, it is clear that their constituent materials are an extremely interesting aid to knowledge. What is more, satisfactory conservation of these objects in museum and patrimonial contexts will depend on the nature and the properties of these materials. They represent a real analytical challenge, as they are often composite materials which were transformed by man and which, over centuries or even millennia, have suffered deterioration in the environment. Mainly responsible for this degradation of works of art are light, water, temperature, salts, chemical pollutants, micro-organisms, insects and man. These agents intervene singly or in various combinations and/or sequences on the objects of the cultural heritage. The aim of this research is to qualify the influence of the ''water'' factor, which is likely to be the source of irreversible deterioration of wood material.

The observations clearly show that the sphere suffered wear and tear resulting from the combined attacks of time and environmental agents: visible deformations of the rings, located cracks, separation of elements, insect attacks in certain areas, etc. Today, the mechanism allowing the rotation of the movable rings is no longer operational. The research task is focussed on the study of the deformation (and its evolution) of the major ring, so called because of its prominent role in the sphere (Section 2), and whose structural integrity is essential to ensure its conservation.

The present study is based on a physical mechanical approach, as the exceptional dimensions of the sphere (more than 3 meters in height) make it an object considered as a true complex structure. Two distinct materials are associated: wood (beech), forming almost the whole object; ''soft'' steel, used for the connection parts (mainly nails). The final aim of the study is to show that the environment in which the sphere is exhibited, and especially the variations in relative humidity (RH) associated with this environment, cause considerable problems which are likely to generate a critical state (i.e. collapse) in the future. It is important to note right now that wood is an extremely hygroscopic material, which means it reacts strongly under the effect of moisture variations. This leads to the deterioration of its mechanical characteristics, with significant losses of stiffness and increasing deformations under the associated application of long-term loads. The concept of wood mechanosorptive creep represents this phenomenon, which is characterized by the effect of a moisture – mechanics – time coupling [2–5].

The use of a numerical tool, based on a model representing the mechanical behaviour of wood, makes it possible to consider the significance of these phenomena on the main load-bearing ring. This model of wood mechanosorptive creep has been validated on results taken from experimental tests on timber elements [6–8] and others on wooden panel paintings [9–11]. The calculation carried out allows the simulation of mechanical loads with variations of the environmental moisture conditions. To define the characteristics of these cycles (amplitude of the RH variations, duration of application), it was necessary to gather information on ''the moisture history'' of the armillary sphere. During the first years of its life, the sphere was exhibited at the ''Museo della Specola'', also located in Florence. It was stored under a shelter outside this museum, and was thus subjected to external climatic conditions. It was then exhibited at the History of Science Museum in the thirties. It is only since 1954 that a modern central heating system has been used inside the museum. This kind of heating system involves many changes as regards the relative humidity of the air, and thus, since then, the current environmental conditions undergone by the sphere have proved to be more harmful than they were before.

Indeed, when stored outside, the sphere was only subjected to low amplitude moisture variations (almost homogeneous RH throughout the year in Florence, as shown in Fig. 8); whereas when the heating is activated in winter, the air is dried. This generates the appearance of moisture cycles between winter and summer seasons. The work, based on a modelling of the life of the sphere, shows that such a heating system, which gives only thermal comfort, is not beneficial for the wooden object.

To carry out this ageing analysis of this wooden structure, preliminary steps have been performed. First, the constitutive elements and the static functioning of the structure have been investigated (Section 2). Then, the characterisation and the identification of the stiffness of the main load-bearing element have been quantified with a real test on a nail-laminated timber beam. The latter has been carried out at constant environmental conditions and without long-term mechanical effects (Section 3). Finally, the numerical computation has been performed to predict the mechanical behaviour of the main load-bearing element, using the results of previous analyses and a simplified environmental scenario as a first assumption (Section 4).

2. Overall static behaviour of the object

The approach used initially requires a clear understanding of the sphere's static behaviour, making it possible thereafter to estimate the internal stresses and deformations undergone by the wood with the passage of time. Indeed, the parametric analyses are valid only if the initial state has been understood. The observations carried out at the museum enabled the development of assumptions aiming to understand how stability was assured and how gravity loads were distributed in the various components. Although the sphere is composed of a vast number of rings of different sizes, made of beech, only two significant rings among this set are structurally load-bearing. These two components, described in Figs. 1a,b, support the whole of the sphere.

The first is the ''main load-bearing'' ring whose lower part rests on A. Most of the internal rings support only their own weight and are attached independently to a 45° metallic axis, fixed on two points, B and C, which are diametrically opposite each other on the main ring. The section of the latter is made up of five wood lamellae which are nailed to each other