Role of the New Technologies on the Artifacts Seismic Vulnerability: The Case of the Bartolomeo Ammannati's "Fontana di Sala Grande", National Museum of Bargello Court – Florence

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In these decades the seismic vulnerability of buildings has been widely investigated, and many different approaches have been developed for their preservation. Museums' collections, instead, achieved interest from research communities only in the very last years. Artifacts are usually vulnerable to seismic excitations, since they can present irregular shape - not easy to be numerically represented - and fragile material. The need to check the seismic vulnerability of artifacts has induced the developments of new techniques aimed at representing their shape and mass distribution through not-invasive approaches, and at simulating their seismic response by means of numerical analyses. This work is aimed at developing a multidisciplinary analysis of an art good, where visual and computer technologies are adopted for the evaluation of its seismic safety. The selected case-study is the "Fontana di Sala Grande" by Bartolomeo Ammannati, currently located under the vaults of the National Museum of Bargello court, in Florence. The sculptures constituting the Fountain have been described through a laser scanner analysis, which has provided a three dimensional digital model. The set of data produced can be visualized in interactive modes, creating a sort of "new reality" showing the possible events according to earthquake phenomena, a kind of reality no one want to see getting real, but at the time useful to know for taking countermeasures. In this work, the 3D model has been adopted to perform a structural analysis aimed at checking the seismic response of the sculpture complex. The digital representation of the sculpture, indeed, has been the starting point to set the structural model to perform the seismic analysis. The seismic input assumed in the analysis has been found by implementing the seismic hazard of the area, according to the current Code classification, through a proper soil modeling, defined after the amplification factor distribution. The research has achieved a reliable evaluation of the seismic safety of the case-study; moreover, it has provided new digital materials, representing a valuable and important art good, which improve the current knowledge level, leading further studies and research to the cultural and scientific community.

Key words:
Seismic assessment of artifacts; Museums' artifacts; Seismic vulnerability; Case-study.

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INTRODUCTION

The art goods represent a priceless asset of the cultural and artistic identity of communities. Nevertheless, their safety is usually neglected, or not effectively pursued. The seismic performance of museums' content is only rarely checked, despite the several losses occurred in the last earthquakes. The evaluation of the seismic vulnerability of art collections encounters two different orders of problems. The first one is the need to account for an enormous number of objects, diverse for shape, material, dimension and staging. Each type of artifacts presents a specific mechanism

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of collapse; a comprehensive vulnerability analysis of the art collections of a museum requires to check all the artifacts, and to classify them according to their vulnerability type. The second problem is to evaluate the safety level of each artifact, since the technical code does not provide any threshold value for the seismic limit state. The new technologies provide a response to the first problem. The digital visual representation, indeed, leads a precise and extensive record of many artifacts with a relatively limited time and effort.

New technologies have already been adopted for artifacts conservation and protection [Abu-Allaban and El-Khalili 2013; Bader et al. 2015; Porzilli and Parrinello 2018]; even in the seismic assessment, the visual technologies have been effectively adopted both for preventive purposes [Athmani et al. 2015] and for post-disaster interventions [Gharechelou and Tateishi 2017]. In this work the digital representation of a group of sculptures has been used for seismic protection; as a matter of fact, the 3D geometrical model provided by a proper laser-scanner survey has been the starting point to set the structural model and to perform the seismic analysis.

The study has been developed inside a research project named "RESIMUS". It is a multidisciplinary research group [Viti 2018], whose goal is combining knowledge on museography, new technologies and anti-seismic methods, in order to prevent risk to the museum collections and artifacts in case of earthquakes. The first artifact assumed as case-study is the Ammannati Juno's Fountain. In 2011 the Department of Architecture of Florence (DIDA) was involved in the exhibition design for the 500th centenary of Ammannati's birth. Besides the exhibition and specific set up, i.e. Mario Nari statues reconstruction [Cerri and Corsini 2015], the main efforts were devoted to the recomposition of the *Fontana di Sala Grande* in the courtyard of the National Museum of Bargello in Florence [Pirazzoli 2011; Zikos 2011].

Initially conceived for the then-Sala Grande (now Salone dei Cinquecento) in Palazzo Vecchio, the so-called concert of statues had a turbulent life. The marble complex was part of a bigger project, but, although several studies [Cerri et al. 2018; Ferretti 2011; Heikamp 1972], there are not clues about the original design. What is certain is that the original project was never finished; the earliest composition was installed in the Sala until 1561, when the single statues were scattered in different locations, all of them belonging to the Medici family. They were reunited at the Museum during the XXI century (see Fig. 1); the above-mentioned exhibition was the occasion for the re-composition and the beginning of a specific study on statues.

Fig.1. The sculptures before the new asset (operated in 2011).

The *Fontana di Sala Grande* is the protagonist of this cross-disciplinary study. The research combines: survey, digital reconstruction, representation, model simulation, physical reconstruction, and preservation. The paper demonstrates how the integration of several technologies and software is necessary to pursue the correct study of a complex artifact, and to develop seismic vulnerability studies.

In the following sections, the main steps faced in investigation are described. At first, the Fountain history has been traced, in order to recompose the sculptures complex in its original asset. The digital survey made to represent the Fountain has been described; the numerical models adopted to describe the sculptures, found on the basis of the digital survey, are described, and the results of alternative time-history analyses are shown with reference to the most vulnerable (slenderest) statue.

ANALYSIS OF THE SCULPTURES, SURVEY METHODOLOGIES, DIGITAL MODELS, PHYSICAL RECONSTRUCTION.

The seismic assessment of artifacts requires a preliminary representation of the objects. Only an accurate representation can provide reliable results in terms of seismic assessment. Therefore, the initial phases of survey, representation, and reconstruction are fundamental for the subsequent steps.

The survey campaign (see Fig. 2) was made in occasion of the exhibition of 2011. The then-goal was the study of the statues and the creation of their exact models, so to allow the correct reconstruction study of the artifacts and the realization of the new set up at the Bargello.

Fig. 2. Images from the 3D Laser Scanner Campaign.

First, a comprehensive survey plan was prepared. The digital reconstruction took almost one year to be completed. To acquire the data, the working group [Verdiani et al. 2012a] used five different research directives: 1) the creation of a digital 3D model composed by continuous surfaces (in order to acquire data and information on metrics about the position and shape of each subject); 2) the realization of a series of 2D drawings; 3) the creation of 3D digital models suitable for the realization of a 3D printed model 4) the simulation of the reconstruction; 5) the production of a digital 3D model used for the hypothetic repositioning in the Palazzo Vecchio.

Three laser scan campaigns were accomplished. In the first survey, it was used a laser scanner Cam2 Faro Photon 120, in the subsequent two surveys, a Nextengine laser scanner was implied (Fig. 3). Due to the different nature of the acquired data, the two data sets were carefully integrated. The final result is given by a series of consequential steps using different software. All the steps involved the generation of numerical models of the statues.

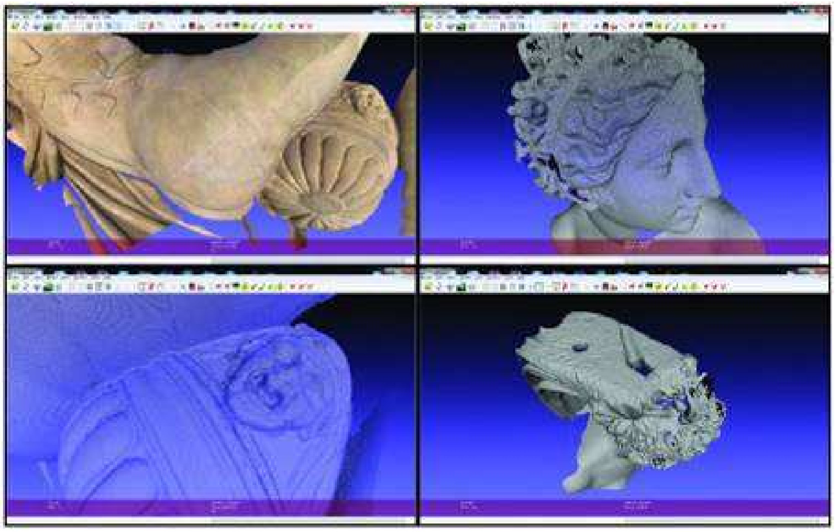


Fig. 3. Details from Nextengine laser scan.

In those phases, the goals were avoiding an excessive simplification of the geometry and obtaining the best possible result from the laser scanning campaigns. The final virtual model of the statues was conceived for several purposes: digital reconstruction, documentation, 3D print, geometrical reconstruction of the layout, base for the physical reconstruction at the Bargello, hypothesis of Ammannati's architectural design for Sala Grande.

The subsequent step was the physical reconstruction of the marble complex, shown in Fig. 4. This delicate phase involved several professional and knowledge. For example, the geometry of the arch (rainbow) derives from the combination of: traditional geometrical deductions, 3D models (see Fig. 5), virtual model hypothesis, museum design studies and solutions [Pirazzoli and Verdiani 2013; Verdiani and Fantini 2012; Verdiani et al. 2012b].

Fig. 4. Digital Model.

Fig. 5. The 3D Print Model inside the exhibition.

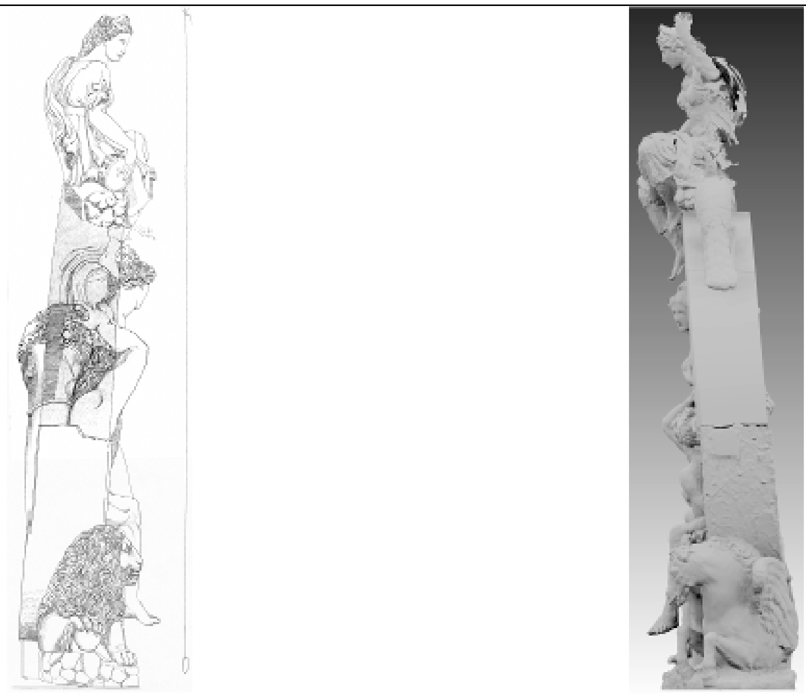


Fig. 6. Comparison between the reconstruction made by Heikamp (1978) and the digital reconstruction (Verdiani, Di Tondo, Fantini 2011).

The final result mirrors the suggestion described by Heikamp [1978] on the Fountain. Confronting its reconstruction with the digital model, shown in Figure 6 (right), the similarity appears very clear. The hypothesis, coming from deductive and traditional geometrical reasoning, is confirmed by multidisciplinary contemporary processes. The final result, shown in Fig. 7, is now conserved under the vaults of the courtyard of the museum [Pirazzoli 2011].

Fig. 7. The current configuration of the Juno's Fountain.

THE SEISMIC INVESTIGATION

Despite the artistic goods continuously prove to be very vulnerable to earthquakes [Parisi and Augenti 2013] the seismic assessment of artifacts has not been adequately faced by researchers; the seismic analysis, indeed, is mostly focused on buildings and constructions, whilst monuments and artifacts are object of conservation purposes. In the last years, however, many contributions [Borri and Grazini 2006; Spyrakos et al. 2017; Wittich et al. 2016; Pascale and Lolli 2015; Berto et al. 2012] have been devoted to the seismic analysis of museums artifacts. The recent developments in the numerical content of both seismic analysis and digital survey induce a natural merge of these issues. Furthermore, the visualization of possible collapse scenarios creates a new reality, increasing the awareness of people about the level of risk.

The structural analysis has been performed on a 3D Finite Element (FE) model consisting of four-nodes tetrahedral isoparametric elements. The FE model used for the analysis has been set from geometrical survey by making a series of changes. As a first step, the virtual model, rendered after the survey campaign, has been reduced in size and definition through the software MeshLab [Cignoni et al. 2008] in order to be used for the analysis. Furthermore, the surface model provided by the laser-scanner survey has been transformed in a volume one, by introducing a set of nodes in the volume inscribed by the statue surface. In Figure 8 the initial and final models of the five statues are shown, together with the number of polygons referred to each model.

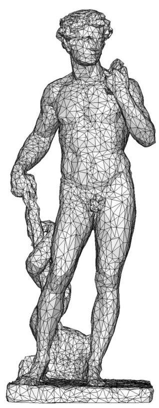
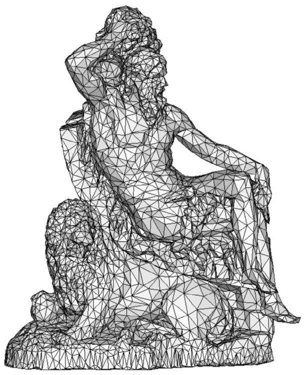
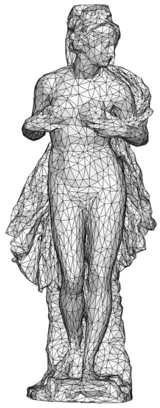
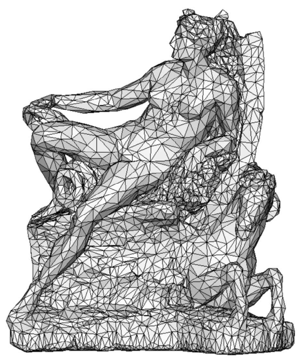
Prudenza	*Arno*	*Cerere*	*Arbia*	*Fiorenza*
				
No. of polygons: 881,000	*No. of polygons: 1.131,916*	*No. of polygons*: 900,000	*No. of polygons:*	*No. of polygons: 975,000*
				
No. of polygons: 10,000 No. of tetrahedrons: 30,600	*No. of polygons: 10,000 No. of tetrahedrons: 32,236*	*No. of polygons: 10,000 No. of tetrahedrons 34,590*	*No. of polygons: 10,000 No. of tetrahedrons: 38,496*	*No. of polygons: 10,000 No. of tetrahedrons: 22,553*

Fig. 8. Models optimization: geometrical models found through the laser scanner survey and the simplified model to use for the seismic analysis.

The seismic input has been represented by a single record spectrum compatible to the elastic spectrum provided by the NTC [2008] for the soil class B. In Figure 9 the seismic input assumed in the analysis is shown.

The seismic response of the sculptures has been found by performing a linear time history analysis on the set Finite Element models through the platform ADINA [2012]. For sake of brevity, only the results found for the statue Cerere, which is the slenderest – and the most vulnerable – of the complex will be shown. Cerere has been represented by a system consisting of the statue and the corresponding pedestal. In the analysis the material has been assumed to be elastic; the marble of the statue has been described through a Young's modulus equal to 50 GPa, a Poisson's coefficient equal to 0.2 and a density equal to 2700 kg/m3. The pedestal, made in masonry, has been represented through a Young's modulus equal to 5 GPa, a Poisson's coefficient equal to 0.2 and a density equal to 1700 kg/m3. Two different analyses have been performed, differing from each other for the interaction between the statue and the pedestal. In the first model (Model_1), indeed, the statue has been assumed as integral with the pedestal, whilst in the second model (Model_2) proper contact elements have been introduced to simulate their interaction.

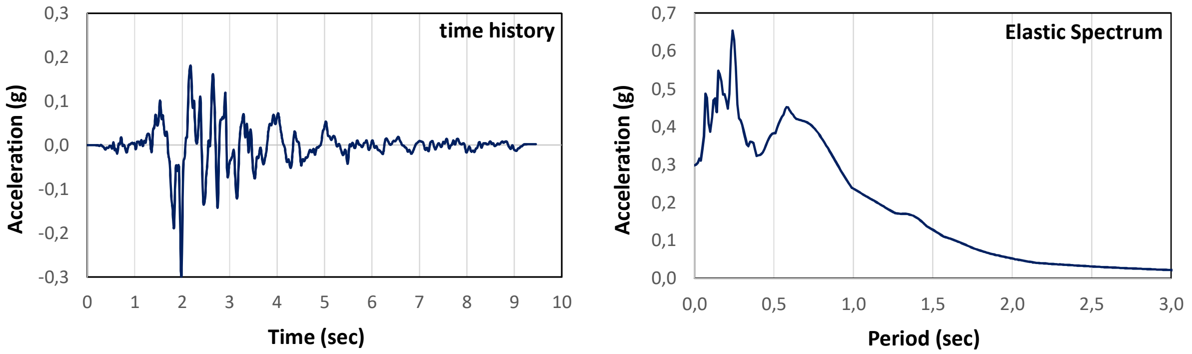


Fig. 9. Assumed seismic input (GMN_HNE).

Fig. 10 shows the response of the system in terms of displacement time-history in both the directions provided by the two models. The displacement refers to the top point of the statue model. As can be observed, the seismic response of the system without contact elements, represented in black, is one order of magnitude smaller than the one provided by accounting for the interaction between pedestal and statue. Since the seismic input has been applied along the X-direction, the response of the system along the Y-direction is negligible. When the Model_2 is adopted, however, a maximum displacement equal to 0,2 mm is attained when the time is around 2 sec, i.e. at the acceleration peak of the time-history.

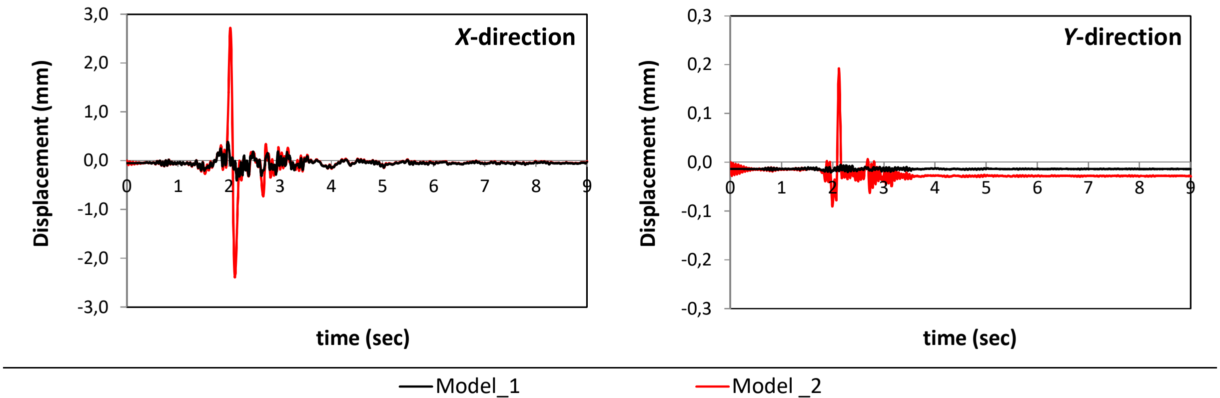


Fig. 10. Top displacement of Venus provided by the two models.

In Fig. 11 the top displacement of the system provided by the two models is represented in the X-Y plane. As should be noted, the interaction between pedestal and statue induces a large non-linearity in the seismic response of the system, despite both analyses have been made by assuming a linear elastic behavior for the material.

The differences between the results found by applying the two models (see Fig. 11) evidence how the adopted assumptions can affect the obtained results. Even if the displacement found for the system is not large enough to activate overturning phenomena [Cerri et al. 2018], it is essential that the analytical model adopted to represent the seismic response of the system is reliable and as much accurate it is possible. Further improvements, such as the non-linearity of the material response and the possible interaction between the soil and the pedestal should therefore be considered.

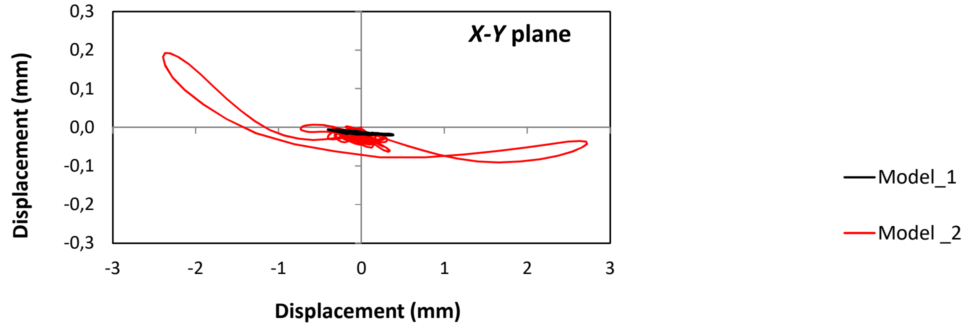


Fig. 11. Seismic response of the system in the X-Y plane.

FINAL REMARKS

This paper presents the first results of a multidisciplinary research focused on the seismic vulnerability of Ammananti's Juno Fountain, currently located in the courtyard of the Bargello Museum in Florence. The history of the Fountain has been traced, and a detailed laser scanner survey has been made on each sculpture of the complex. The geometrical models provided by the laser scanner have been assumed as started point to set the structural models for the dynamic analysis.

The seismic input has been represented through a real ground motion spectrum-compatible to the elastic spectrum provided by the Italian Code for the site soil. Two different time-history analyses, differing for the assumption made regarding the interaction between pedestal and statue, have been performed and compared on the sculpture Cerere, which is the most vulnerable (slenderest) one. In the first analysis the seismic response of the system "statue + pedestal" has been represented by assuming a linear behavior of the material and a perfect cohesion between statue and pedestal. In the second analysis, instead, proper link elements have been introduced between the statue and its pedestal, in order to take into account their mutual interaction.

The results found through the two models resulted to differ very much from each other, since the top displacement found by accounting for the interaction between pedestal and statue is almost ten times larger than the one found neglecting such interaction. The comparison between the two-results series showed that the interaction between pedestal and statue induces a large non-linearity in the seismic response of the system, despite both analyses have been made by assuming a linear elastic behavior for the material.

Since the two adopted analytical models, both linear-elastic, provide results so different from each other, further analyses should be performed in order to investigate the effects of different assumptions, such as the nonlinear behavior of the sculpture, different interaction models between the statue and the pedestal and by including the possible interaction between the soil and the pedestal. Moreover, a more representative seismic input, i.e. a larger number of ground motions, should be included in the investigation.

The study is the result of the combined application of different branches of knowledge, and it shows how the numerical representation of artifacts is related to its seismic assessment and preservation. The artwork, the monument, the ancient masterpiece is nowadays seen in a very advanced way according the needs of preservation and value, at the same time there is still a certain way to be done to reach a condition that set free the most important heritage pieces from the risk of natural events like earthquakes. A digital set of information, based on digital surveys, 3d modeling and virtual analysis creates the right base to face this challenge. This articulated digital approach overlaps and enhances the perception of the Cultural heritage item, creating a new image of it, something almost fluid, clear demonstration of how these items are not eternal, but fragile in front of unpredictable catastrophic events. In this way, these new realities can play an essential role not only in the representation of artifacts, but even in their comprehension, monitoring, and – furthermore – in involving the community in their preservation. The map of the possible risk sources is not a mere omen, but a real opportunity for protecting and preserving the cultural heritage patrimony.

The new opportunities of preservation and protection coming from this new scenario of knowledge is maybe one of the most significant step in this century, a new reality starting from a real condition and from a real environment, passing by a full digitalization and virtualization of the whole context and then developing virtual possibility and theoretical events, just to go back to the real world with real solutions for preventing a range of possible disasters. A new reality of digital/real preservation and knowledge that overlap the past, static approach and moves to new possibilities of protection for the heritage.

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