Florence and the Renaissance art works: the importance of the seismic safety

Stefania Viti | stefania.viti@unifi.it
Department of Architecture (DIDA), University of Florence
Francesco Trovatelli | francesco.trovatelli@unifi.it
Department of Architecture (DIDA), University of Florence

Abstract
Florence is known all over the world for its history, monuments, Museums, and artworks. Unfortunately, such precious manufacts are not always adequately protected against natural hazards. Works of art, indeed, are very vulnerable to seismic effects, due to their irregular and slender shapes, and their fragile materials. All these reasons make them vulnerable to seismic events even when they do not achieve a destructive intensity. The current Technical Codes point out such vulnerability, despite providing guidelines not completely adequate to prevent the seismic damage. In this frame, a research activity has started within the Department of Architecture of Florence aimed at investigating the dynamic response of artworks to seismic events, including both simplified form-filling and more detailed Finite Element analyses. In this work, the seismic performance of the marble statue "Oceanus" by Giambologna has been assessed by adopting three different analytical models.

Keywords
Art works, Cultural heritage, Seismic performance, Seismic safety, Florence.

The research activities

The seismic hazard is one of the main dangers threatening the Italian cultural asset. Indeed, artworks may easily present an intrinsic vulnerability, due to their irregular shape, slenderness, and fragility[1]. The seismic vulnerability of Italian artworks has been highlighted by the recent seismic events (Emilia Region 2012, Aquila 2009, Central Italy 2016). A proper assessment of the seismic vulnerability of artworks cannot be pursued regardless of their staging and the buildings where they are exhibited[2]. Indeed, the buildings, such as the windows and the pedestals[3] which are used for artifacts' exhibition, are supposed to have a protective function, saving them against all possible dangers; unfortunately, they may instead become their main source of hazard[4]. Recently, many contributions have been dedicated to the vulnerability assessment of artworks; most of them were focused on the seismic response of specific case-studies[5] [6] [7] [8], whilst few general contributions have been referred to miscellaneous art collections[9] [10]. The current research project[11] focuses on the seismic vulnerability of artworks, and it comprehended both single pieces-of art and entire collections.

The most important case-study faced within the research project is the National Museum of Bargello, in Florence, which contains a large variety of collections of a great artistic value. A special attention has been paid to the effective amount of seismic excitation experienced by each object-of-art at the occurring of an earthquake compatible to the assumed seismic hazard of the area, and to the role plaid by the staging in its seismic response. As regards the first issue, the amount of seismic excitation (i.e. acceleration and displacement) experienced by the artworks has been checked by investigating both the features of the foundation soil[12] and the role of the building in the propagation of the seismic waves. This latter assessment has been pursued by placing some seismic station along the building heigh[13], both in some exhibition rooms and in the adjacent Volognana Tower. The results of the experimental test have been validated through a numerical analysis, made on a Finite Element model of the exhibition room.

As regards the role of the artwork's staging, it has been accurately assessed by investigating the role played by the base restraint of the artwork and by considering its dynamic response with and without the staging itself.

In this paper, some results of the research group are briefly shown with reference to the giant statue "Oceanus" made by Giambologna.

The analyses made on the statue "Oceanus" by Giambogna

The statue "Oceanus" has been selected to perform analytical analyses, made adopting alternative procedures, differing from each other for geometrical model, calculation hypotheses and computational effort. Oceanus is a giant marble statue made by Giambologna between 1572 and 1576, and it is currently located in the courtyard of the Museo of Bargello in Florence. It has an heigh equal to 3.31 m, a weight of about 2 tons, and it is made of Carrara's marble. Figure 1 shows a view of Oceanus, together with the three structural models used in this

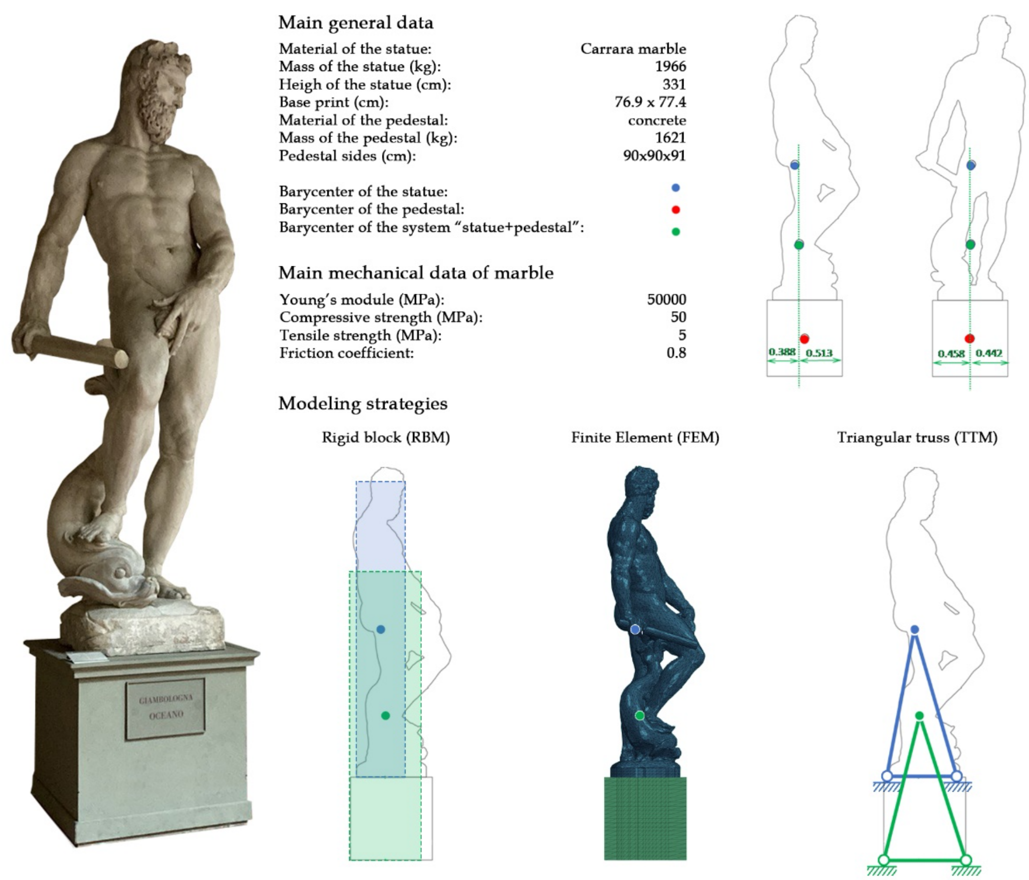


Fig. 1 The statue of Oceanus, main data and adopted modelling strategies.

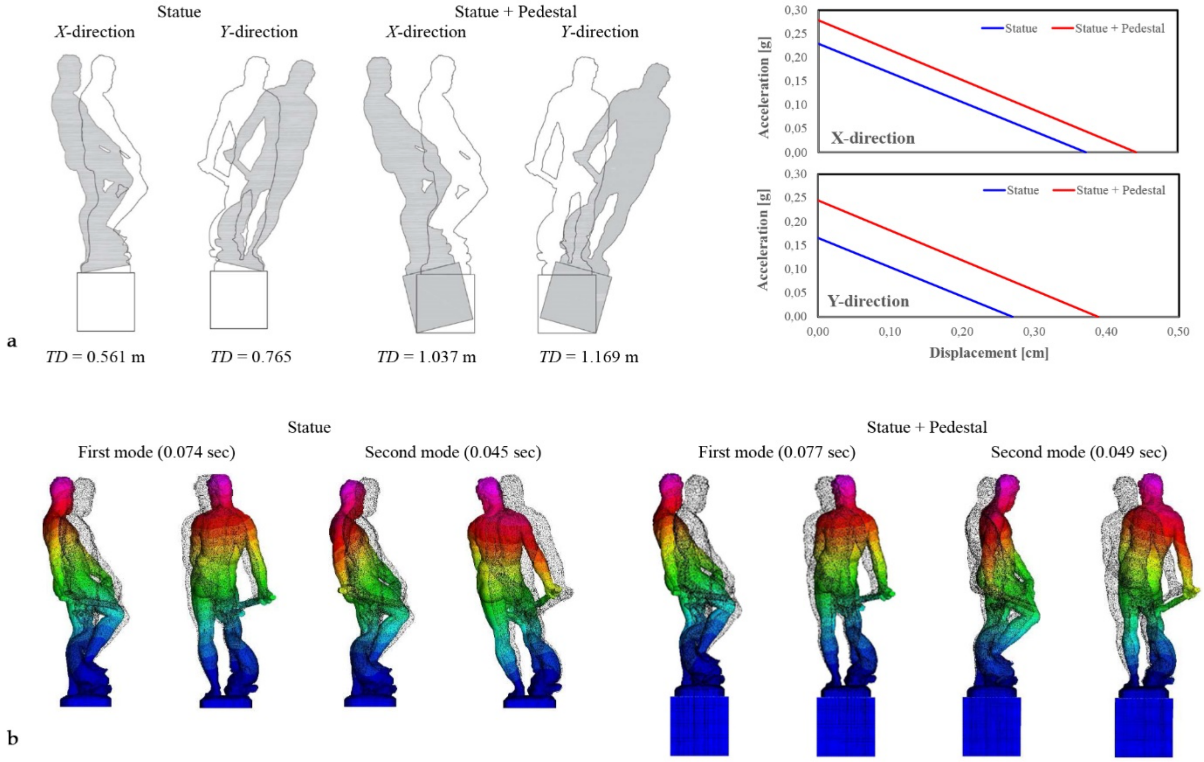


Fig. 2 a) Limit displacement at the overturning and capacity domains of the rigid block models; b) modal shapes, evaluated through the FE model, of the first two vibration modes with and without basement.

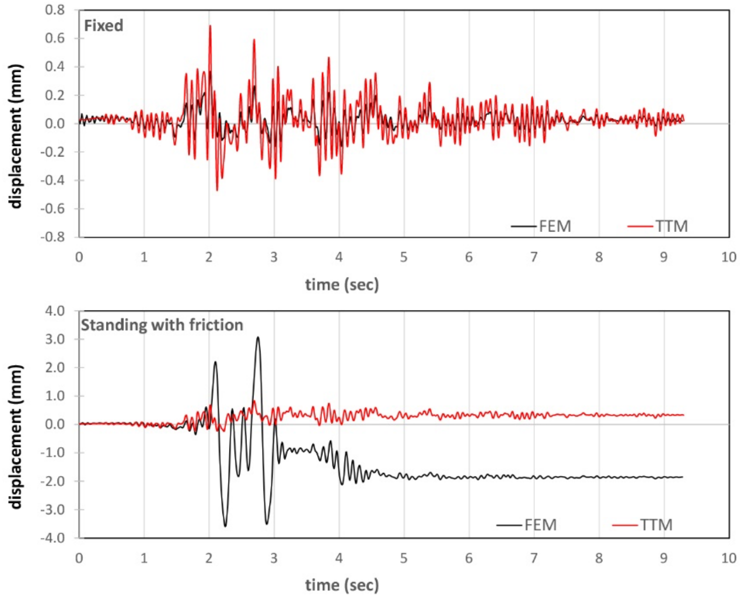
research activity and the main mechanical information on the Carrara marble; such information has been found by the research group performing proper lab-tests[14].

The "rigid block" model (RBM), represented in Figure 1, is the simplest representation of a standing body. It assumes a rigid behavior of the system, which is described through few data, easily deducible by the geometrical model: the mass, the center of mass (*MC*) position and the dimensions of the base of the system, i.e. the possible rotation points for overturning. Despite its simplicity, the rigid block model can provide interesting information, such as the limit displacement of the *MC* at the overturning for the considered options (i.e.: main direction, eventual inclusion of the pedestal). When the expected seismic acceleration is known, the overturning limit condition can be used to determine the limit horizontal acceleration, and, consequently, the capacity domain. In this case, the seismic demand has been found by assuming a soil class B, a ground acceleration, A_g, equal to 0.1659g (corresponding to the *Life Safety* limit state for a class of use c_u=2, a nominal life equal to 50 years and a Return Period equal to 949 years) and a Fundamental Period equal to 0 sec, i.e. the sculpture has been assumed as perfectly rigid. Figure 2a shows the main results provided by the Rigid Bock model, while in *Tanganelli et al. 2021*[15] further information on the analysis can be found.

The Finite Element (FE) analysis is the most representative and versatile analytical approach to the dynamic response of artworks. The FE model (FEM), shown in Figure 1, has been set by simplifying a geometrical model based on a detailed laser-scanner survey. As it is known, the effectiveness of the FE models depends on the assumptions made in the analysis[16 17]. The simplest assumptions consist of linear behavior of material and perfect restraint conditions; in this case, the analysis can be performed even through standard software platforms, and it provides basic but very important information, such as the modal properties of the model, its tensional involvement under the assumed seismic excitation, and the elastic stiffness of the system. Figure 2b shows the first two vibrational modes of the system; the knowledge of the modal behavior of the system is fundamental to choose the analyses to perform, since it shows: *i)* which is the direction more sensitive to horizontal actions, *ii)* which is the role of the torsional behavior of the system, and *iii)* how much the pedestal can affect its dynamic response.

In order to get a more effective representation of the dynamic response of the system under seismic excitation, a special attention has to be paid to the restraint conditions of the system. Recent studies[18] showed that the friction acting between the base of the statues and their support plays a fundamental role in their dynamic response; the introduction of such interface action, however, leads a non-linearity in the analysis not easy to represent.

The effect of the base friction between statue and pedestal has been checked by performing a nonlinear time-history analysis through the Abaqus software[19]. The results shown in Figure 3 refer to the horizontal displacement of *MC* found by assuming – as seismic excitation – the record of the earthquake occurred in Friuli in 1976 (Gemona, code: GMN_HNE_01), having a PGA equal to 0.255g and an elastic spectrum compatible to the one provided by the current Code (NTC 2018) for the case-study. The plot shown in Figure 3a refers to the horizontal displacement of the statue assumed as perfectly fixed, whilst Figure 3b shows the same results by considering the effect of the base friction. The "triangular-truss" model (TTM), shown in Figure 1, has been recently proposed[20] to introduce the friction contribution between the system base and the support without facing relevant computational effort. It has been developed within OpenSEES platform, and it represents the statue as a SDOF system, consisting of three trusses connected by as many nodes; one of the nodes is located at the center of mass of the system, while the other two ones are placed, respectively, at the intersection between the cross section of the statue (including or not the pedestal) and its support. The model is based on some very simplified assumptions, such as the 2d response of the system. Furthermore, its stiffness needs to be set on the basis of a preliminary modal analysis, made on the elastic FE model. Under such assumptions, however, the model provides very interesting results, leading to check the effects of the friction between the base and the investigated system with a low computational effort. Figure 3 shows the displacement time-history found for the system made by the statue under the same Gemona ground motion. As can be noted, the results provided by the FE and the TT models have a good agreement for the fixed system, whilst they present relevant differences when the base friction is introduced. A more extended comparison between the two models is provided in Trovatelli *et al.* 2022[21]. As a result of the performed investigations, it can be concluded that the choice of the model to assume for analysis plays a fundamental role in the quality of the obtained results. A proper analysis, therefore, requires the adoption of various models, in order to check different matters of the dynamic response of the investigated system, without neglecting any fundamental aspects of its dynamic behavior.



a

b

Fig. 3 Comparison between the horizontal displacement of Oceanus' Mass Center under the Gemona ground motion (ground motion code: GMN_HNE_01) provided by the FE and the TT models; a) Fixed system; b) Standing with friction system.

Main achievements and further developments

The research activity is aimed at providing a systematic procedure to assess the seismic vulnerability of artworks. As regards the artworks exhibited in Museums, a special attention has been paid to the role of the museum building in the seismic waves transmission and to the staging adopted for the exposition. Important achievements have been made in defining the seismic input acting on the single manufacts and in the classification of the art collections as a function of the expected seismic damage at the occurring of earthquakes. In this work some results are presented, with reference to the analyses made on the statue *Oceanus*. Three different structural models have been shown, and their main properties have been presented and explained. The effectiveness of the results provided by each model should be checked through the comparison with the results of experimental testing, which is the next step forecasted by the research project.

[1] Lowry MK, Farrar BJ, Armendariz D, Podany J (2007). Protecting Collections in the J. Paul Getty Museum from Earthquake Damage. WAAC Newsletter 29: 16-23.

[2] Podany J (2017). When Galleries Shake: Earthquake Damage Mitigation for Museum Collections. GettyPublications, pp 248. ISBN 978-1-60606-522-8.

[3] Wittich CE, Hutchinson TC (2016). Experimental modal analysis and seismic mitigation of statue-pedestal systems. Journal of Cultural Heritage 20 (2016): 641-648.

[4] Viti S, Reinhorn AM (2020). Monumental buildings used as museums: protection or danger for the artifacts?, Procedia Structural Integrity, vol. 29: 40-47, ISSN: 2452-3216, doi: 10.1016/j.prostr.2020.11.137.

[5] Borri A, Grazini A (2006) Diagnostic analysis of the lesions and stability of Michelangelo's David, JCH 7, 273–285.

[6] Berto L, Favaretto T, Saetta A, Antonelli F, Lazzarini L (2012). Assessment of seismic vulnerability of art objects: The "Galleria dei Prigioni" sculptures at the Accademia Gallery in Florence, J C H 13, 7–21.

[7] Cimellaro GP, Tanganelli M, Viti S Rotunno S (2019). Dynamic analysis of artifacts: validation of numerical models. Proc. of 7th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering. Crete, 24-26 June 2019.

[8] Viti S, Pintucchi B, Rotunno T, Tanganelli M (2020). The seismic analysis of Cerere at the Museum of Bargello. Bulletin of Earthquake Engineering, 18(6): 2635-56, ISSN: 1570-761X, doi: 10.1007/s10518-020-00802-6.

[9] Parisi F, Augenti N (2013). Earthquake damages to cultural heritage constructions and simplified assessment of artworks. Engineering Failure Analysis 34, 735–760.

[10] Ciampoli M, Augusti G (2000). Vulnerabilità sismica degli oggetti esibiti nei musei: interventi per la sua riduzione. In: Vulnerabilità dei beni archeologici e degli oggetti esibiti nei musei. A cura di D. Liberatore, CNR-GNDT.

[11] Viti S, Tanganelli M (2019). Resimus: A research project on the seismic vulnerability of museums' collections. In: 7th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, COMPDYN 2019, National Technical University of Athens, vol. 2, pp. 2819-2829.

[12] Sapia V, Materni V, Giannattasio F, Marchetti M (2019). Esplorazione geofisica del sottosuolo: primi risultati nel centro storico di Firenze. In: "RESIMUS Un progetto rivolto alla vulnerabilità sismica delle opere museali", a cura di Stefania Viti, DIDAPRESS, Firenze.

[13] Azzara RM, Pellegrini D, Cardinali V, Viti S, Tanganelli M (2022). Assessment of the acceleration floor spectra through dynamic identification: the Museum of Bargello in Florence, Structural Integrity Procedia, XIX ANIDIS Conference, Seismic Engineering in Italy, Assisi (in print).

[14] Tanganelli M, Coli M, Cimellaro GP, Marasco S, Cardoni A, Noori AZ, Viti S (2019). Dynamic analysis of artifacts: experimental tests for the validation of numerical models. In: COMPDYN 2019, M. Papadrakakis, M. Fragiadakis, vol. 2, pp. 2865-2877, ISBN:978-618-82844-7-0.

[15] Tanganelli M, Galassi S, Viti S (2021). Simplified analyses for the model setting of sculptures: the "Oceano" by Giambologna. in: COMPDYN 2021, Atene, 27–30 June 2021, COMPDYN 2021, pp. 1-10.

[16] Cerri G, Pirazzoli G, Verdiani G, Rotunno T, Pintucchi B, Viti S, Tanganelli M (2018). Seismic Assessment of Artefacts: The Case of Juno's Fountain of The National Museum of Bargello. In: Florence Heri-Tech 2018 - The Future of Heritage Science and Technologies, Florence (Italy), 16-18 May 2018, IOP publishing, vol. 364.

[17]Domaneschi, Marco; Cimellaro, Gian Paolo; Viti, Stefania; Tanganelli, Marco (2022). Protection of art works to blast hazards: the Fountain of Neptune in Florence. INTERNATIONAL JOURNAL OF MASONRY RESEARCH AND INNOVATION, vol. 1, pp. 1-1, ISSN:2056-9459.

[18] Monaco M, Guadagnuolo M, Gesualdo A. (2014). The role of friction in the seismic risk mitigation of freestanding art objects. Nat Hazards, 73: 389–402.

[19] Hibbit HD, Karlsson BI and Sorensen EP (2012). ABAQUS user manual, version 6.12 Dassault Systemes Simulia Corp. Rhode Island, USA.

[21] Conti S (2020). Protezione sismica di opere d'arte: l'uso di basi lubrificate con polvere di grafite e il caso studio della statua di Cerere. Tesi di Laurea in Ingegneria Edile-Architettura, Università di Catania.

[21] Trovatelli F, Barbagallo F, Marino EM, Tanganelli M, Viti S (2022). Modeling marble artworks: the statue "Oceanus" by Giambologna. Florence Heri-Tech 2022, 16-18 May 2022 (in print).