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SEISMIC VULNERABILITY OF MUSEUMS' COLLECTIONS: A CASE-STUDY

Silvia Lelli[1], Maria Gatto[2], Marco Tanganelli[1], and Stefania Viti[1]

[1,3] Dipartimento di Architettura (DIDA), Università degli Studi di Firenze
via della Mattonaia 8, 50121 Firenze (Italy)
e-mail: silvia.lelli@stud.unifi.it, {marco.tanganelli,stefania.viti}@unifi.it

[2] Direzione regionale Musei della Toscana, Ministero della Cultura
Museo Archeologico Nazionale, via Margaritone 10, 52100 Arezzo (Italy)
maria.gatto-01@beniculturali.it

Abstract

Conservation of art works is a strategic issue of scientific and seismic research. The safety monitoring of Museum's collections is fundamental for their conservation. However, a detailed assessment of the seismic safety of all the exhibited item is tough to achieve, due to the required amount of time and resources. In these years, therefore, the quick and simplified approaches for the seismic safety assessment have been object of a special attention for academics, scientists, and Museums' managers. In this work, a qualitative approach for the seismic assessment of Museum's collections based on forms filling is proposed. The proposed approach is aimed at understanding the safety of single items, staging and exhibition rooms. The analysis has been made on a case-study, i.e. the National Archaeological Museum "Gaio Cilnio Mecenate", placed in Arezzo. The Museum offers a large variety of collections, with items which differ from each other for material, dimensions, shapes and seismic vulnerability. Even the adopted staging presents a wide variety, including windows of various types, shelves and pedestals. The presented study provided the assessment of the seismic safety of the items exhibited in some of the Museum's rooms; moreover, it represents a simple and general method which could easily be applied to other Museums and exhibition buildings.

Keywords: Museums' collections, art collections, seismic performance, seismic safety.

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1 INTRODUCTION

Art works play a special role in the cultural and economic asset of Italian country. Despite being evidence of the history and the culture of the community, they increase the value of the touristic allure, representing a precious portion of the National heritage. They can differ from each other for age, shape, material, dimension, state of conservation, and so on. The possible problems related to their protection and conservation, therefore, are not easy to manage, since different art works can face different risks.

Art-collections exhibited in Museums are easier to protect, comparing with outside art-works, such as those in the squares or within the palaces' facades [1]. Museums' collections, indeed, can be protected against theft, vandalic attacks, atmospheric agents and most part of the potential common risks. Even Museums' collections, however, can be exposed to risks, especially when historical buildings are used as Museums. At the occurring of ground motions, the buildings containing the collections can, sometimes, represent more a damage source than a protection [2].

The large number of artworks exhibited in the Museums does not help their preservation. The planning of a effective and systemic safety assessment would require a preliminary analysis of the risk vulnerability of each item, that would be very expensive to make. Right now, most part of interventions are limited to the seismic protection of outstanding masterpieces, such as – just to mention some of them – *Bronzi di Riace* (www.enea.it/it/seguici/news/basi-antisismiche-per-sicurezza-bronzi-di-riace), *Pietà Rondanini* by Michelangelo [3], and *Giovinetto di Mozia* [4].

In these last decades, however, various studies have been made to face the problem of the preservation of art collections made by many items [5-8] having different features, materials and vulnerability sources.

The present research focuses on the issues of conservation and seismic protection of artifacts on exhibit within museums and historical buildings, i.e. site-specific museums. It started some years ago within the project RESIMUS [9], focused on the seismic vulnerability of the collections exhibited at the International Museum of Bargello in Florence. It comprehended both specific analysis of case-studies [10], including some experimental testing [11,12], and general form-filled procedures to check the seismic vulnerability of the collections [13].

In this work, the proposed procedure has been implemented, by enforcing the classification criteria and by adapting the general approach to a specific case-study, i.e. the National Archaeological Museum "*Gaio Cilnio Mecenate*" in Arezzo [14]. The proposed assessment is based on some macro-parameters easy to check, in order to be developed by the personnel in charge of the Museum management, without engaging engineers or other professionals.

The "*Gaio Cilnio Mecenate*" Museum has cooperated with the Department of Architecture for the filling-forms procedure, which has been applied to two of the 26 exposition rooms. The works has leaded to find the most vulnerable items within the considered collections, providing a suitable database to use for assessing the seismic and – potentially – further risks sources.

2 THE CASE-STUDY: ART COLLECTIONS EXHIBITED AT THE NATIONAL ARCHAEOLOGICAL MUSEUM "GAIO CILNIO MECENATE"

2.1 The Museum

The National Archeological Museum "*Gaio Cilnio Mecenate*" (Figure 1) is placed in the old San Bernardo Monastery. The building is situated in Arezzo's historical down-town, next to the ancient Roman amphitheater.

Figure 1. Views of the amphitheater and the Museum.

The amphitheater was given from *Carlo Magno* to the Arezzo's bishop; then, it was given to the *Azzi* family, and (in 1333) to *Bernardo de' Tolomei*, founder of the *Benedettini Olivetani*. He commended the construction of the Monastery, and the contiguous church (see Figure 2).

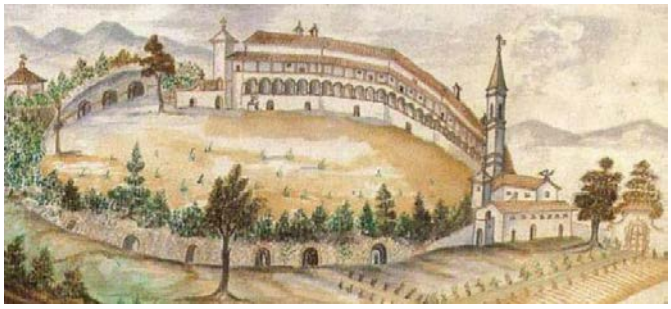


Figure 2. Part of watercolor by Donato Montaiuti (1768) kept in the Arezzo's library.

Figure 3. Damages after the IIWW bombing.

The Monastery included the remains of the amphitheater, which induced the curvy trend to the Monastery façade. Next to the North wall of the church, in the XV century was made a quadrangular cloister, which has been partially destroyed in the centuries.

The current entrance of the Museum is placed in the South branch of the cloister. The Monastery was used by the Olivetan monks until 1783. Successively, it experienced many changes, in property and in use, becoming, in 1866, part of the Italian State property, which gave it in use to Arezzo town. The complex history of the Museum went along with architectural transformations as much important, which substantially change the original layout.

The current layout can be considered to have started in 1914, with the archeological excavations. In 1931 the ancient structures were dug up. Due to a water table, only the remains until one meter over the original Roman plan were dug. The building become the location of the Museum, and hosted both the archeological remains found in the urban excavation and some further rich collections acquired by the Museum along the time. The Museum was inaugurated in 1937; during the IIWW the building was gravely damaged. The church, the cloister and the western branch were completely destroyed (see Figure 3), as much as the archeological finds which were fixed at the walls.

In 1949 the rooms have been restored, reorganized and enhanced. Under the direction of superintendent Guglielmo Maetzke the Museum opened again in 1951, September 1st.

2.2 The exhibited collections

The National Archeological Museum *Gaio Cilnio Mecenate* is one of the most important permanent exhibitions of archeological goods in Tuscany. The current arrangement of the Museum dates back to 1951, after the building restoration. In 1973 it became a National Museum.

Today the Museum is made of 26 rooms (see Figure 4), collecting about 13,000 items. The ground floor hosts 14 rooms, which contain, with a topographic order, items referred to Arezzo's history, starting from its foundation in the Etruscan age.

At the upper floor there are further 12 rooms, containing the prehistorical section, the thematic collections (such as bronze and jewels) and some further collections from private source. One of the most famous items exhibited at this floor is the *Cratere di Euphronios* (510 b.C.) shown in Figure 5, i.e. a big red figure Athenian vase used for mixing wine, honey and water, coming from a rich anonymous grave.

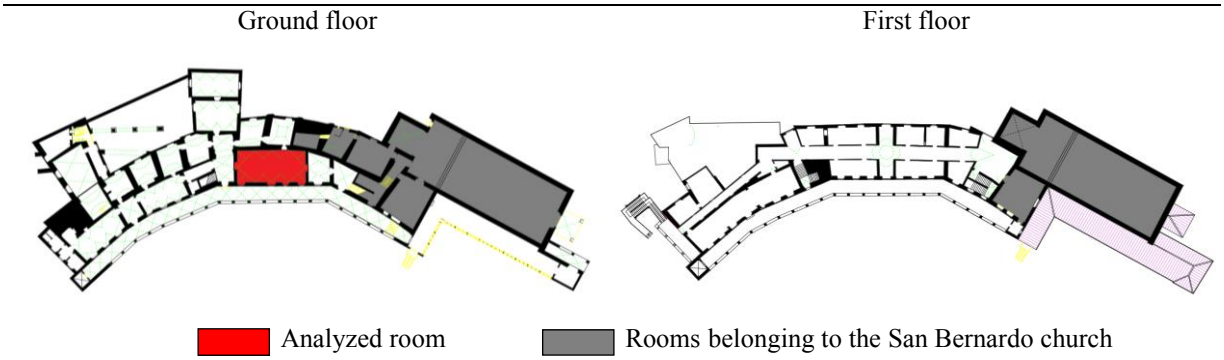


Figure 4. Plans of the Museum.

a.*Cratere di Euphronios* (510 b.C.) b. *Ritratto miniaturistico in crisografia* (III century)

Figure 5. Some items exhibited in the Museum.

3 THE PROPOSED ARTWORKS' CLASSIFICATION

3.1 The proposed form-filled procedure

The proposed classification is aimed at assessing the seismic vulnerability of each single item as it is exhibited within the Museum. For this reason, it includes even the assessment of the seismic safety of the display cabinet/window, the one of the rooms and of the building itself. Finally, all the collected information merges in a final form, which resumes the main results found through the performed classification, providing a synthetic assessment of the seismic safety of the Museum's content. Consequently, the classification consists of five different forms for each item:

1st form. Description and information gathering of the building (building form).
2nd form. Description and analysis of the exhibition room (room form).
3rd form. Description and analysis of the display cabinet/window (display form).
4th form. Description and analysis of the item (item form).
5th form. Seismic assessment of the item within its staging (vulnerability form).

Despite the work is aimed at assessing the seismic vulnerability of the collections displayed in the Museum, the filled forms have been organized in order to collect even general information, not strictly related to the seismic safety of the items. Indeed, the proposed procedure could be easily adopted as a comprehensive management device, which works as a support for various sources of risk, such as flood, aging, etc.

Building form. It collects all the information regarding both the Museum organization and the building where the Museum is hosted, such as:

- Museum's general information (address, contacts, Director's info, opening days, emergency plans, personnel involved, visitors' flow).
- Building features and seismic performance (geometric survey, design drawings, archive number of the technical plans, diagnostic data about structure and soil, existing studies).
- Exhibited collections (how many, number and value of each one, where they are displayed).
- Rooms' location within the Museum.

As regards the building's information, the form provides a comprehensive list of data which are required to check its seismic performance, such as the technical drawings, the mechanical properties of the materials, the licenses given during the construction and the conservation processes, etc. Such data have filed in order to represent an archive where all the useful data can be found, even those not strictly related to the project purpose.

Room form. This form must be made for each of the exposition rooms, and collects information regarding the location within the building, the technical drawings (plan and section with indication of entrance and exit, safety devices, fire emergency plan), the description of the contained items and collections, with the respective displayers.

The room form is equipped with photos of the woom's walls, of the entrances, and all the exhibition cabinets. In this work, only one room has been presented, called "*Arezzo etrusca*", which will be described in the next paragraph.

Displayer form. This form has been substantially revised comparing to the original approach proposed in the project *RESIMUS,* which was focused on each item only. The pedestal and/or the display cabinets, indeed, deserve a dedicated seismic analysis, since they can amplify the seismic acceleration, reducing the safety of the contained items. In the proposed classification,

each displayer is classified as: window, pedestal, panel and didactical panel. Each of these types of displayers can face different damages due to seismic excitation, and their seismic safety has to be checked consequently. For windows and pedestals, it's important to investigate the interaction with the floor and with the contained items [11,15] which can present a huge variety of technological solutions. As regards the panels, their safety is strictly related to their connection to the walls, and – as a consequence – to the wall's condition and behavior. Even this form comprehends various types of data, such as photos and archive specifications, and proper parameters appositely provided, such as shape, material, age, geometry, state of conservation, etc.

Item form. It is the main phase of the proposed procedure. The criteria provided for the classification have been set on the basis of the outcome of previous studies [13,16] which identified various collapse mechanisms as a function of the main parameters, which can be resumed through the following classification:

- General information: archive code, age, source, associated displayer.
- Type classification: dimensions, weight, geometry, material, slenderness, interaction with the displayer.
- State of conservation.

On the basis of the type classification, different information has to be added, in order to identify the most probable collapse mechanism. The seismic vulnerability of the item is assessed on the basis of the filling work. Even this form is enhanced with photos and further graphic material, when available.

Vulnerability form. The assessment of the vulnerability of the system "item+cabinet" is driven on the basis of the data collected in the previous forms. Namely, the structural adequacy of the building and of the room is a necessary requirement to proceed to the items' seismic vulnerability. The outcome of the *building* and the *room* forms are not combined to the vulnerability assessment of the item and the respective displayer, but they are only a pre-requisite, as shown in Figure 6. If there would be considerable lack of data regarding the structural behavior of the building, or if its seismic performance would be unsatisfactory, further investigation and/or consolidation would be required on the building.

In the vulnerability assessment, a special attention has been paid to the possibility to improve the seismic safety of each item through immediate interventions, such as changing the position of some item or displayers.

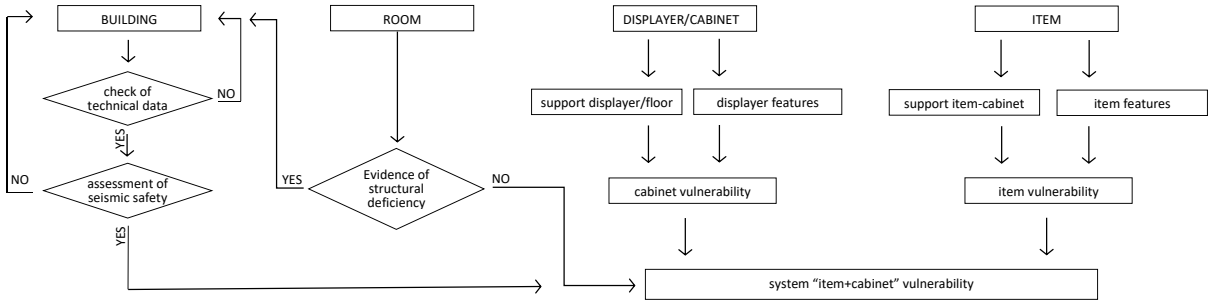


Figure 6. Form-filled procedure for assessing the seismic vulnerability of the displayed items.

3.2 Case study: the "*Frammento di testa equina in terracotta*"

In this paper, for sake of brevity, only one item has been reported as case-study, together with its displayer, and a synthesis of the data collected for the room where it is exposed. In this paragraph only the main information has been shown; the data referred to the Museum, such as a more extensive description of the work, can be found in Lelli 2022 [17].

Room form. The current arrangement of the room "*Arezzo Etrusca*" has been made in 2013 by Dr. Silvia Vilucchi. The room, shown in Figure 7, is placed in the central part of the ground floor of the Museum; it has a surface of 77.30 sqm, 4 windows and three doors. As it is shown in Figure 8, the room has some lighting and sensor devices fixed at the ceiling and the walls.

Figure 7. Views of the room "*Arezzo Etrusca*".

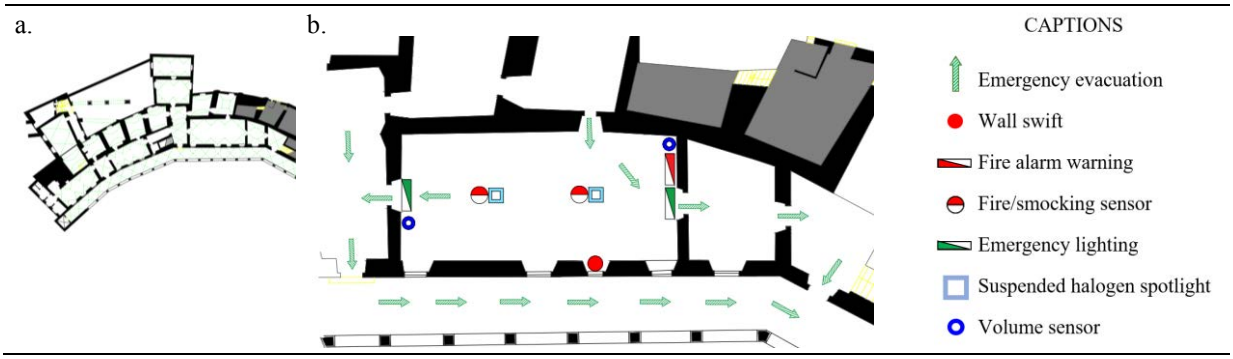
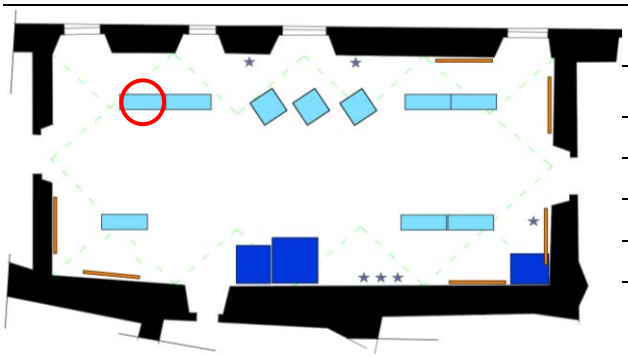


Figure 8. Room "*Arezzo Etrusca*": a. Location; b. Main devices.



displayers' caption

symbol	type	number	number of contained items
	windows	10	82
	pedestals	3	2
	wall panels	16	16
	didactical panels	7	-
	case-study		

Figure 9. Room "*Arezzo Etrusca*": location and classification of the displayers.

Figure 9 shows the location and the classification of the displayers in the room, with the number of the contained items. In the *room* form, all the ID number of each item is reported and associated to the respective displayer.

Displayer form. The displayer consists of a special pedestal, made in Plexiglas, which follows the shape of the item. It stands on the glass shelf of the window, laying, in turn, on the floor. The assessment of the seismic safety of the displayer, therefore, is not immediate, since it requires to analyze the stability of both the window, comprehensive of its shelves, and the Plexiglass device, beside the relationship between the floor and the window, and the window and the pedestal and the interaction between adjacent windows and adjacent pedestals. The possible interaction between the displayer system and the item will be face in the *vulnerability form*. Figure 10 shows two displayer images, together with the main information collected in this form. As can be seen, the window is placed next to another one, having the same dimensions, which can certainly interfere with its vulnerability in case of seismic excitation.

The dynamic response of the window could interfere even with the vulnerability of the item's pedestal.

system	material	dimension	shape	slenderness	weight	device interface	interference	interference' effects
windows	glass	medium	regular	medium	medium	no	yes	high
pedestal	Plexiglass	small	peculiar	high	low	no	yes	medium

Figure 10. Display of the "*Frammento di testa equina in terracotta*".

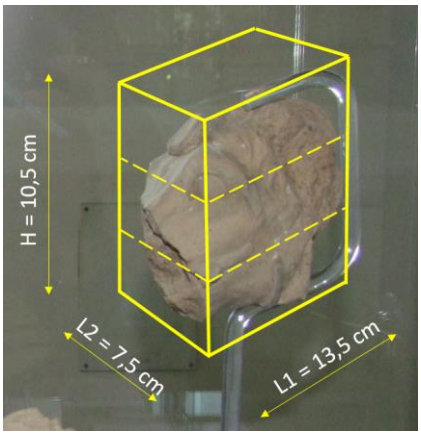
Item form. The item consists of a sculpture in terracotta, dating back to the Etruscan age. The item is only a part of the original sculpture; anyway, it is well conserved, and with a great value. The item is fragile, and it could easily face damages in case of overturning. The object itself (i.e. without considering its staging) is compact, and, therefore, it does not result to be vulnerable to overturning. Its main vulnerability is related to the displayer, which leads a raising of the center of mass of the item, with the consequent increase of its overturning vulnerability.

The main information on the item is collected in Figure 11, whilst a more detailed classification can be found in Lelli 2021 [17]. As can be observed, the geometry of the item is assessed through a simple and visual analysis. The object is faced as a geometrical simple shape; its attitude to overturning is assessed by checking the slenderness of the item, and the position

of its center of mass (MC), i.e. whether MC belongs to the bottom, central or top part of the item. Another important assessment concerns the state of conservation of the item, which include the integrity of its volume and its surface.

3d model

Geometric classification



L1: maximum depth of the item along the X-direction

L2: maximum depth of the item along the Y-direction

H: item's heigh

CM: center of mass

	Parameters	Description	Assessment
General info	Name	Frammento di testa equina in terracotta	
	ID	87668/S2.V2.R3s - 4	
	source	Etruscan	
	age	Etruscan age (IX-I century BC)	
	material	terracotta	
Geometry	Dimension	Small (5-30 cm)	
	Weight	Light (0.2 – 8 kg)	
	Shape	Oval/elliptical	
Conservation	Entirety	scarce	good
	Volume integrity	good	
	Surface integrity	good	
Overturning attitude	center of mass position	medium (1/3 H < MC < 2/3 H)	scarce
	Eccentric parts	none	
	Medium slenderness	height slightly larger than base	
	Footing surface	flat	
	Material deformability	low	
Displaying	Display	window	Subjected to the device performance
	Standing device	yes	

Figure 11. *Frammento di testa equina in terracotta.*

Vulnerability form. In this last step of the analysis, the seismic vulnerability of the system "item+displayer" is assessed on the basis of the data collected in the former forms.

The vulnerability has been checked with reference to the case-study, i.e. to the overturning collapse mechanism. As it can be noted, the vulnerability of the system "item+displayer" is not just the combination of the vulnerability of the item and the displayer by itself. In this case, the overturning vulnerability is related to the raising of the mass center of the item due to the Plexiglas pedestal. The location of the pedestal within the window does not substantially change the item's stability: the height of the shelf is low, so than there is not considerable seismic amplification, but the window does not avoid the possible overturning of the item.

In the work, two different assessments have been performed: the intrinsic one, referred to the quality of the equilibrium of the system, and the effects of possible interferences, with the structural and non-structural components of the building, with the adjacent items and displayers and with the visitors. For each critic situation, the possibility to provide an immediate so-

lution or improvement has even been assessed. The synthesis of the assessment has been shown in Table 1.

Table 1. Vulnerability assessment of the system "item+display"

INTRINSIC VULNERABILITY: HIGH

		yes		no	Possible moving			Required
		adequate	not adequate		X	Y	Z	improvement
Base-anchoring	Floor-window			X	X	X	X	X
	Window-pedestal			X	X	X	X	X
	Pedestal-item		X					X
Stability	Item	X						
	Item+pedestal			X	X	X	X	X
	Item+pedestal+window			X	X	X	X	X

VULNERABILITY DUE TO THE INTERACTIONS: HIGH

Type of interaction	NO	POSSIBLE	INTERFERENCE REDUTION		
			immediate	impossible	Possible/not easy
Adjacent windows		X			X
Adjacent items		X	X		
Structural collapse		X			X
Non structural collapse	X				
Visitors actions		X			X

4 CONCLUSIONS

The paper presented the assessment of the seismic vulnerability of the art collections exhibited at the National Archaeological Museum "*Gaio Cilnio Mecenate*", placed in Arezzo. Such assessment has been made by means of a simplified approach, consisting of filling proper forms properly set by the Authors. The form-filling approach has been described, and its adoption on the Museum has been shown for one of the considered items, i.e. the "*Frammento di testa equina in terracotta*".

The proposed approach represents a useful instrument to check the seismic vulnerability of extensive art collections, since it leads to collect meaningful information without a dedicated specialistic work. Furthermore, the safety-sensitive data can easily integrate the general information already owned by the Museums' management; in this way, the proposed method can become a useful tool for the administrative management.

The presented filled-form method should be further validated, by comparing the results of the achieved simplified assessment with experimental data, obtained by performing proper dynamic tests on some case-studies.

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