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Prioritizing risk for cultural heritage through social value: a participatory framework

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ABSTRACT

Evaluating exposure to natural hazards is crucial for risk management, particularly for cultural heritage, where multi-faceted values like social, aesthetic, spiritual, and historical dimensions make assessment complex. This study presents a participatory, quantitative approach to evaluate the social value of cultural heritage buildings based on a pairwise comparison survey administered to a community of citizens. Moreover, the correlation between social value and other simple proxies is explored. The intangible impact is defined as a combination of social value and a physical property typical of the natural hazard considered, e.g., water depth for floods. The method is applied to the art city of Florence (Italy) where a community of interest joined the survey. The results show that museums are assigned significantly higher social values than places of worship, with UNESCO-listed heritage valued up to 30 times higher than nationally listed buildings. Social value correlates most strongly with ticket price (Spearman's $r = 0.68$), followed by number of visitors. Canonical correlation analysis links social value more strongly to a combination of variables ($r = 0.75$), with ticket price and museum status as the most influential factors. Mapping flood magnitude weighted by social value shifts the most at risk areas away from the river, underscoring the importance of intangible cultural values in risk prioritization.

1. Introduction

Natural hazards cause each year huge monetary losses and fatalities [1] with significant concerns about climate change prospects for hydro-meteorological hazards [2]. Among the elements exposed to natural hazards and threatened by potential losses, cultural heritage has an exemplary role due to its tangible and intangible values, such as social, cultural, historic and artistic values [3,4].

Exposure to hazards is usually defined as the location, quantity, and type of elements potentially affected, e.g., people, livelihoods, social or cultural assets. It is recognized that "risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system to the hazards", therefore the risk determinants change over time due to climatic and socio-economic factors [5]. Moreover, the definition of risk by IPCC Sixth Assessment Report acknowledges the diversity of values and objectives associated with human systems that may suffer adverse consequences [5]. For cultural heritage there is a need for incorporating intangible and tangible heritage values into risk assessment methodologies for several reasons, such as the establishment of priorities for protecting cultural heritage asset, and risk management [6–8]. Intangible impacts refer to the costs of natural hazards that are difficult or impossible to quantify in monetary terms, such as effects on health, cultural heritage, or the environment. These impacts are often excluded from cost assessments of natural hazards, resulting in incomplete and potentially biased evaluations

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[9,10]. The overall value of cultural heritage combines use values and non-use values. Use values include extractive, i.e., market values, labour and income, and non-extractive use values, i.e., aesthetic and recreational values [3,4]. Non-use values include, but are not limited to, social, spiritual, historical and authenticity values [3,4].

The assessment of also the non-use values of cultural heritage becomes then crucial in risk analysis and prioritization of mitigation measures. Depending on the scale of the assessment, different approaches have been adopted in literature. At large-scales, i.e., national, regional or catchment scales, the degree of legislative protection or listing level has been often used to assign different grades of exposure values [11,12]. A recent work developed a framework aiming at integrating social vulnerability and landscape concepts into the assessment of cultural heritage vulnerability to flood hazards [13]. The work emphasizes that climate-related hazards disturb both tangible and intangible aspect of cultural heritage. However, in the majority of cases when multiple cultural items at risk are considered, most of the attention is devoted to the characterization of the hazards [14–16] or of the vulnerabilities [17,18] and cultural heritage values are not included in the analysis.

Among the few studies that address the problem of cultural value quantification for risk assessment purposes, Arrighi et al. [19] adopted the number of visitors as a proxy for intangible cultural heritage value at urban scale. The value of authenticity, one of the criteria for the recognition of 'outstanding universal value' by UNESCO [69], based on heritage attributes has been considered in a study on the Palatine Hill in Rome [20]. Economic methods aiming at estimating total economic value have been proposed for single cultural items [21]. Among economic valuation methods are hedonic pricing, travel cost, and contingent valuation (e.g., willingness to pay) methods which derive from environmental economics [22,23]. These methods are recognized as complex and expensive to apply and, more importantly, unable to assess non-use values [24]. Recently Analytic Hierarchy Process (AHP) has been adopted to determine the weights of distinct non-use values for several sites in the Ming Great Wall in China [25].

If historic and artistic values can be evaluated by experts, although with some subjectivity [26], social value is not linked to an expertise but is more linked to individual perception, community identity, and sense of place [27]. Social value refers to a broader non-financial aspect of cultural heritage linked to well-being of individuals and communities.

In general, participatory approaches, also recalled as community-based approaches, foresee the involvement of local community, citizens and stakeholders for contribution to the solution of socio-environmental problems through a bottom-up approach [28,29]. Participatory approaches have emerged in the last decades as a crucial tool for disaster risk reduction, with significant advantages such as the sharing of knowledge, the inclusion of minorities and improved dialogue between stakeholders, but also limitations, such as unequal power level between participants, limited information retrieval, and time consumption [30]. An increasing number of agencies engaged in Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) are adopting community-based approaches to assess and mitigate risks. However, externally imposed framing can direct community engagement toward a predetermined objective, thereby potentially constraining the scope of participatory methods and limiting their capacity to elicit and incorporate the full extent of local knowledge [31,32].

Participatory approaches have been widely adopted in risk assessment and management contexts, such as for vulnerability analysis [33,34], risk mapping and planning [35–39] and awareness [40]. Examples of community participation for cultural heritage, however, have been limited so far to governance and management of heritage sites [41–43]. Except for a recent literature example aiming at identifying priorities for conservation [25] quantitative methods have rarely been applied to intangible aspects of cultural heritage valuing. Moreover, in the work by Fan et al. [25], Analytic Hierarchy Process was used to determine the relative importance of the different categories of non-use values and the survey was administered to experts, not to a community of citizens.

This work aims at creating a participatory modelling framework to quantitatively assess non-use (intangible) value of built cultural heritage for exposure analysis to natural hazards. The involvement of the community through participation aims at quantifying with a relative scale the social value of cultural heritage. The social value of cultural heritage refers to the meaning and significance collectively attributed by a community, shaped by individuals' upbringing, life experiences, interpersonal relationships, communication, and travel. This value is dynamic, evolving over time in response to societal changes and cultural shifts [27]. Here, social value is used as a metric for exposure, to distinguish between more valuable and less valuable assets according to community perception. Therefore, social impact is here defined as the combination of expected physical damage of the cultural heritage building and its social value.

The analysis of social impact is performed by combining 'classical' physical hazard analysis and exposed intangible value. Particularly, this work deals with the social value of built cultural heritage, i.e., heritage buildings, adopting the pairwise comparison method at the community level. The pairwise comparison method overcomes some of the most common limitations of participatory approaches, enhancing inclusion of minorities, transparency, and providing quantitative information. In fact, unlike participatory approaches where outcomes are often shaped by group consensus, potentially leading to the marginalization of minority views, the outcome of the pairwise comparison method reflects the view of participants who individually express their preferences. Moreover, the pairwise comparison method is more effective in helping users accurately express and apply their decision priorities, it facilitates more efficient task completion by users and has practical advantages in decision-making contexts, particularly in tasks involving the elicitation and application of user preferences [44]. The estimated social value of cultural heritage is then compared with other quantitative measures such as the number of visitors, ticket price etc. to understand potential correlations. The methodological framework is applied to the historic city centre of Florence—a UNESCO World Heritage Site—in the context of flood hazards. Florence experienced severe flood damage to much of its cultural heritage in 1966. Although the event occurred decades ago, its memory remains vivid in the historic centre and within both local and international communities, reflected in periodic thematic exhibitions and the enduring high-water marks on historic buildings. This makes Florence an ideal case study for testing this new methodology. As such, this work offers one of the first examples of quantitatively assessing cultural heritage exposure to natural hazards through a participatory approach.

2. Materials and methods

To evaluate the intangible impact of natural hazards on cultural heritage at the city scale, three key steps are necessary. As commonly agreed by the scientific community, risks result from the dynamic interactions between hazards and the exposure and vulnerability of the affected system. These components of risk are dynamic and subject to change over time due to climatic and socio-economic factors [5].

Three types of heritage are usually recognized under UNESCO frameworks: tangible cultural heritage (such as monuments or buildings), intangible cultural heritage (such as social practices, performing arts, oral traditions, etc.), and natural heritage (such as areas of outstanding natural beauty or with biodiversity importance) [45,71]. Beyond this physical classification, different types of cultural heritage can hold both tangible values (such as use-values) and intangible values (such as symbolic or non-use values).This study focuses on the intangible value of tangible cultural heritage, i.e., cultural buildings or monuments, and excludes other forms of heritage, i.e., intangible and natural heritage.

The first step of the analysis involves the spatial characterization of the hazard in terms of the probability and magnitude of the selected natural phenomenon. The second step requires identifying the intersection between the hazard and the location of cultural heritage items, which allows for assessing their physical exposure to the specific phenomenon (e.g., using seismic hazard maps or landslide susceptibility maps). Physical exposure analysis can initially be interpreted as a binary classification—whether or not an item is affected by the natural phenomenon. However, more detailed spatial analyses can assign additional magnitude-related information to the exposed elements, such as peak ground acceleration, flood depth, etc [46,47].

Typically, the magnitude of an event serves as the key input for vulnerability models, which estimate the potential damage to affected assets. From empirical evidence [48] and existing models for cultural heritage [12,18,49], vulnerability—defined as the propensity of exposed elements to suffer adverse effects—increases with event magnitude.

Finally, the adverse impact assessment requires consideration of the value of the exposed element, whether tangible (i.e., monetizable) or intangible.

In this framework, because the values of cultural heritage are hardly monetizable and intrinsically linked to community well-being, we adopt social value as a measure of its importance. Consequently, the adverse impact on cultural heritage extends into the social dimension—one of the multiple recognized intangible aspects. The framework combines a standard hazard-exposure analysis with the social value to estimate the intangible damage to the community because of cultural heritage exposure. The impact of a natural hazard on cultural heritage can lead to a loss of the community's sense of place and identity, resulting in significant psychological distress. At the same time, the direct tangible damage to cultural heritage remains an active area of research for many hazards.

The third step of this framework is, therefore, the evaluation of the social value of the cultural heritage asset. Fig. 1 presents a schematic summary of the risk components addressed in this study. As illustrated in the figure, the intangible impact of cultural heritage lies at the intersection between the physical dimension and the social dimension. It is important to note that while the analysis of the physical dimension is hazard-specific and requires an appropriate metric, e.g., water depth for floods or peak ground acceleration for earthquakes, the evaluation of social value is independent of the type of hazard considered. The social value is calculated through a participatory approach as described in the next section.

2.1. Social value

In this work the social value, i.e., one of the many non-use values of cultural heritage is considered. The social value of cultural heritage can be defined as the value generated collectively within a community of individuals as a result of person's upbringing, life experience, interpersonal relationships, communication or travel. This value therefore evolves with time, influenced by societal changes and cultural dynamics [27]. The quantitative assessment of social value is conducted in this work through a participatory approach by involving a group of citizens, identified as members of a community. Communities are typically classified into three groups: communities of practice, communities of interest and communities of place [50]. The selection of the community was based on

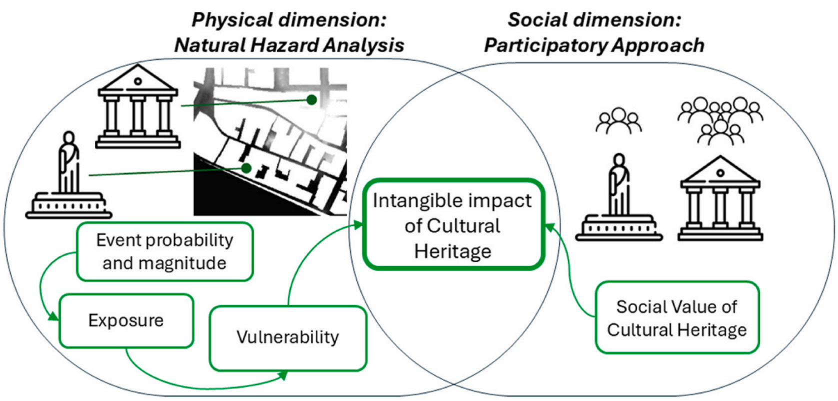

Fig. 1. Methodological scheme to evaluate the intangible impact of built cultural heritage by combining the physical and social dimensions of risk.

the specific purpose of participation—namely, the reasons why people choose to participate and the type of knowledge they contribute [51]. In this study, involving 'ordinary' citizens proved practically difficult due to limited opportunities for engagement, technical challenges, and sampling constraints. Therefore, in agreement with the UNESCO office (the main stakeholder in the study area), it was decided to involve citizens who are part of a community of interest. This selected community shares a common perspective and aims to preserve and promote cultural heritage in the city. It consists of members of cultural associations who actively contribute to the UNESCO Management Plan [52]. Although they may not have formal expertise in heritage studies, they are aware of the importance of protecting local heritage. This type of selection is often referred to as purposive sampling, wherein individuals are chosen based on specific roles or perspectives [53]. Participation was further facilitated by the trust these associations have in both the UNESCO office and the University. More details about the community involved are provided in the case study description.

The main challenge of the proposed approach is the need to assign a specific (relative or absolute) value to each cultural item within the entire potentially affected cultural site, e.g., the historic centre of Florence, in order to support optimal risk management strategies. To this respect, assigning relative social values (i.e., ranking the cultural items in terms of social value for a reference community) may be considered already as a first viable and useable solution to the above challenge. The participative approach described below has been designed to obtain precisely this solution.

The participation is structured around a pairwise comparison by means of web-based survey platform developed for the purpose of the research [54], aimed at establishing a 'consensus ranking' over a given list of items. The platform allows each participant to express a preference on the social significance of the cultural heritage item, thus incorporating diverse perspectives into the assessment and ensuring that all voices are included. This approach ensures that all voices are not only represented but also weighted equally, preventing any dominance by a particular segment of the community. The pairwise comparison is preceded by the following question "Which among the following cultural heritage items would you recommend to a friend?" The question does not explicitly refer to a particular non-use value and assumes that a recommendation to a friend embeds and combines many criteria that would make the overall individual value of the cultural heritage item, particularly the affection to a certain item and the identity of a community. It is important to recognize that each respondent brings his/her own subjective perception of the social value of cultural heritage. Such individual biases are intrinsic to the concept of social value itself and, rather than being eliminated, are embraced as part of the diversity of perspectives that the method seeks to capture. Moreover, by maintaining a uniform and neutral question throughout, we minimize the risk of response bias introduced by question phrasing. The pairwise comparison method for collecting judgment data is largely used in the context of Multi-Criteria Decision Analysis (MCDA) [44,55,56]. In the web survey, each participant is asked to make comparisons between pairs of cultural heritage items, assigning a net preference to one of the two objects within the pair. In this way, the preferences expressed can be transformed into quantitative information for assigning a score, and thus a weight to each item, even those that received little or no preference [57]. Each pair presented to the participant contains two cultural heritage items, each accompanied by a photo, name, and short description (Fig. 2).

The pairs are extracted from the full list of cultural heritage items using the "Swiss tournament" method [58]. The Swiss tournament method is an adaptive sampling approach used to select comparison questions. It prioritizes two types of pairs: those that have received fewer responses and those with similar relative importance. Compared to purely random sampling, the Swiss method extracts more information from the same number of responses. In fact, while the total number of possible cultural heritage pairs may be substantial, each participant may be required to answer a limited set of questions, provided there is a sufficiently large pool of participants. Participants are asked to reply to a minimum number of questions for reaching at least two times the number of possible

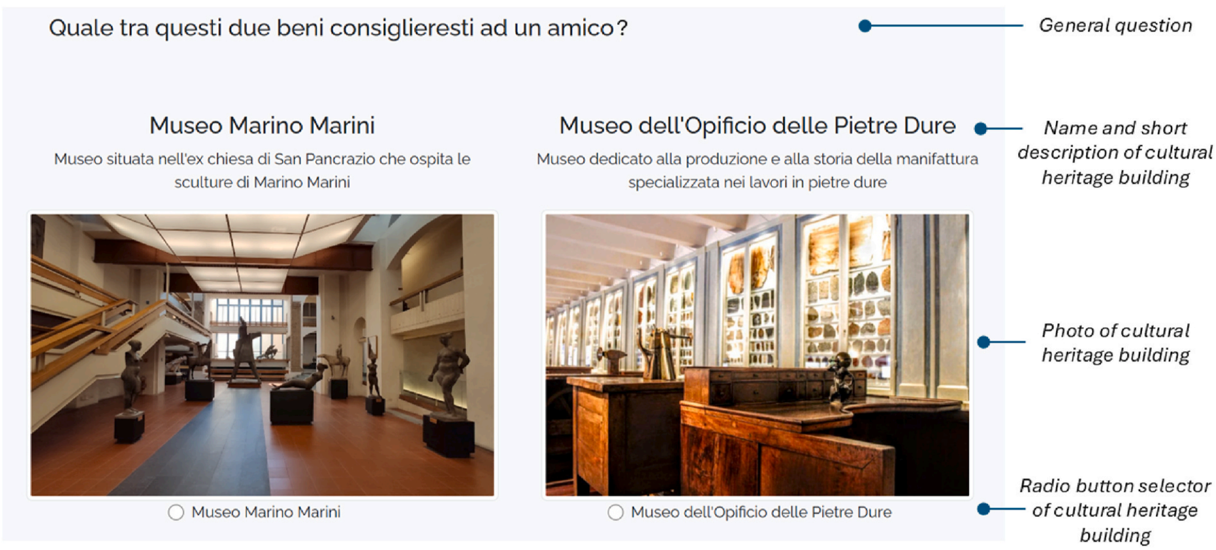

Fig. 2. Screenshot of a web page of the pairwise comparison (in the original Italian language) with a description of the components on the right side.

combinations among pairs. Assumed that n is the number of elements included in the analysis, i.e., the Cultural Heritage buildings, the total number of combinations N is given by the following formula N=(n(n-1))/2.

The authors designed and implemented the pairwise comparison survey using custom code and open-source tools [54]. The code underwent a normal debugging phase as commonly done in software development and tested before the involvement of the community. The survey was hosted on Amazon AWS and made accessible to participants through a public web link via their browsers. The source code was written in Python, and the "Flask" web framework was employed to manage both backend and frontend functionalities. Flask was integrated with a MariaDB database to manage and store survey data. Custom scripts facilitated data retrieval and insertion, as well as the implementation of methods for combining criteria and presenting questions to participants. The web interface was built using the "Bootstrap" toolkit, which incorporates HTML, CSS, and JavaScript components, to design form fields and controls. Python scripts were also developed for data analysis, enabling retrieval from the MariaDB database, construction of a pairwise comparison matrix, and application of the equations and methods described later. When a single combination of pairs receives more than one response, an aggregate score is obtained by calculating the geometric mean of the individual scores assigned by each participant [59] then the pairwise matrix is assembled (Eq. (1)) [60].

$$\mathbf{A} = \begin{pmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & 1 & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & 1 & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & a_{n3} & \dots & 1 \end{pmatrix} \tag{1}$$

where a_{ij} represents the relative score of the i-th element over the j-th element. The matrix, of size *N* x *N*, has the following properties:

$$a_{ij} > 0, a_{ij} = \frac{1}{a_{ji}} \tag{2}$$

i.e., all elements are positive, and the lower triangular matrix contains reciprocal elements relative to the upper triangular matrix.

The eigenvalues of the pairwise matrix A are the scores obtained by the survey and represent the relative importance of each cultural heritage item in terms of social value.

Since the social value obtained through a participatory approach requires significant effort, encompassing careful organization, planning, and collaboration with community members, simple Spearman's rank correlation, Pearson's linear correlation and canonical correlation analysis are performed to determine whether social value, as expressed by the community, can be estimated using alternative proxies. Canonical correlation analysis is a way of inferring information from cross-covariance matrices. If there are two vectors of random variables X, Y, and there are correlations among the variables, then canonical-correlation analysis finds linear combinations of the vectors U, V with coefficients A, B that have a maximum correlation with each other [61]. The tested variables are objective, measurable and accessible as geographic features. The selected variables are: (1) the spatial extent of the cultural heritage building, (2) the number of annual visitors, (3) the price of the ticket, (4) being or not a place of worship, (5) being or not a museum, and (6) the distance of the building from the centroid of the historic centre. The fourth and fifth variables are Boolean. The sixth variable aims at exploring the role of the distance from the most ancient part of the city centre as a sort of periphery factor. Variables that are not significantly correlated to the social values as estimated form the pairwise comparison experiment, i.e., those with a p-values >0.05, are deleted from the canonical correlation analysis in the second step. The variables adopted for the canonical correlation analysis are pre-processed by applying a Z-score normalization as commonly used in this kind of analysis [62,63].

$$Z = \frac{X - \mu}{\sigma} \tag{3}$$

Where Z il the normalized variable, X is the original variable, μ and σ are the mean and the standard deviation of X respectively.

2.2. Exposure analysis and intangible impact

The physical exposure to natural hazards is commonly obtained by intersecting a georeferenced layer of cultural heritage with a hazard map. Cultural heritage can be described by different geometric features such as points, mainly adopted at large spatial scales [11,12], or polygons more common at municipal or local scales [64].

In this work the physical exposure is characterized only for river flood hazard as an example of the potential hazards affecting cultural heritage with a relevant spatial variability even within a single historic city centre. Flood hazard is usually defined as the probability of occurrence of a flood in a certain area. The flood magnitude corresponds to the respective inundation depths and or flow velocities. Inundation depths can be either modelled or estimated after an event based on quite long-lasting mud marks on the buildings [48]. The typical form of a flood vulnerability model is a monotone increasing function *f* of the variable *H* (flood depth), $D = f(H)$. Currently, there is limited available information to determine how vulnerable individual heritage assets are based on specific flood characteristics [49]. Therefore, in the absence of detailed studies that could at least distinguish between heritage asset types (e.g., museum, library, historic building, etc.), a precautionary approach is commonly adopted: during the overlay of flood-prone areas with the heritage asset layer, a damage value of D = 1 is uniformly assigned, regardless of the flood magnitude [65]. Since flood vulnerability models for buildings associate greater impacts with increasing event magnitude, and specific vulnerability models for cultural heritage are rarely found at the urban scale, we use flood depth for a given event as a proxy for flood damage. Consequently, the intangible impact is calculated as the flood depth (H) weighted by the social value (S).

$$Intangible\ impact(i) = H(i) \cdot S(i) \quad (4)$$

Where H is the flood depth in correspondence to the i-th cultural heritage building and S its social value.

2.3. Case study

The method is demonstrated for the historical city centre of Florence (Italy). The historical city centre of Florence is a UNESCO World Heritage site since 1982 and hosts one of the highest density of artworks and cultural buildings within its surface. The exposure analysis for cultural heritage is carried out within a research project between the University of Florence, the UNESCO office and the Hydrographic District of the Northern Appennines, with the final goal of understanding natural hazards risk and resilience of the city with respect to its heritage component. The UNESCO perimeter extends for 532 ha, and it is managed by the UNESCO office that oversees issuing the management plan of the site aimed at the conservation and promotion of cultural heritage. Within this perimeter, 10 heritage buildings are classified as having Outstanding Universal Value (OUV) according to the first criterion of the UNESCO Convention, thus indicating that their social value is already well-recognized. However, many other buildings are classified as cultural heritage, ca. 170 within the overall municipal boundary. The UNESCO management plan identifies floods as one of the most important natural hazards threatening cultural heritage since 1966, when a catastrophic flood event occurred [70]. To identify a reference flood hazard map, the historical water marks engraved in the stones of many buildings have been used; these water levels are considered as a worst-case flood scenario while engineering works to prevent floods are undertaken [66].

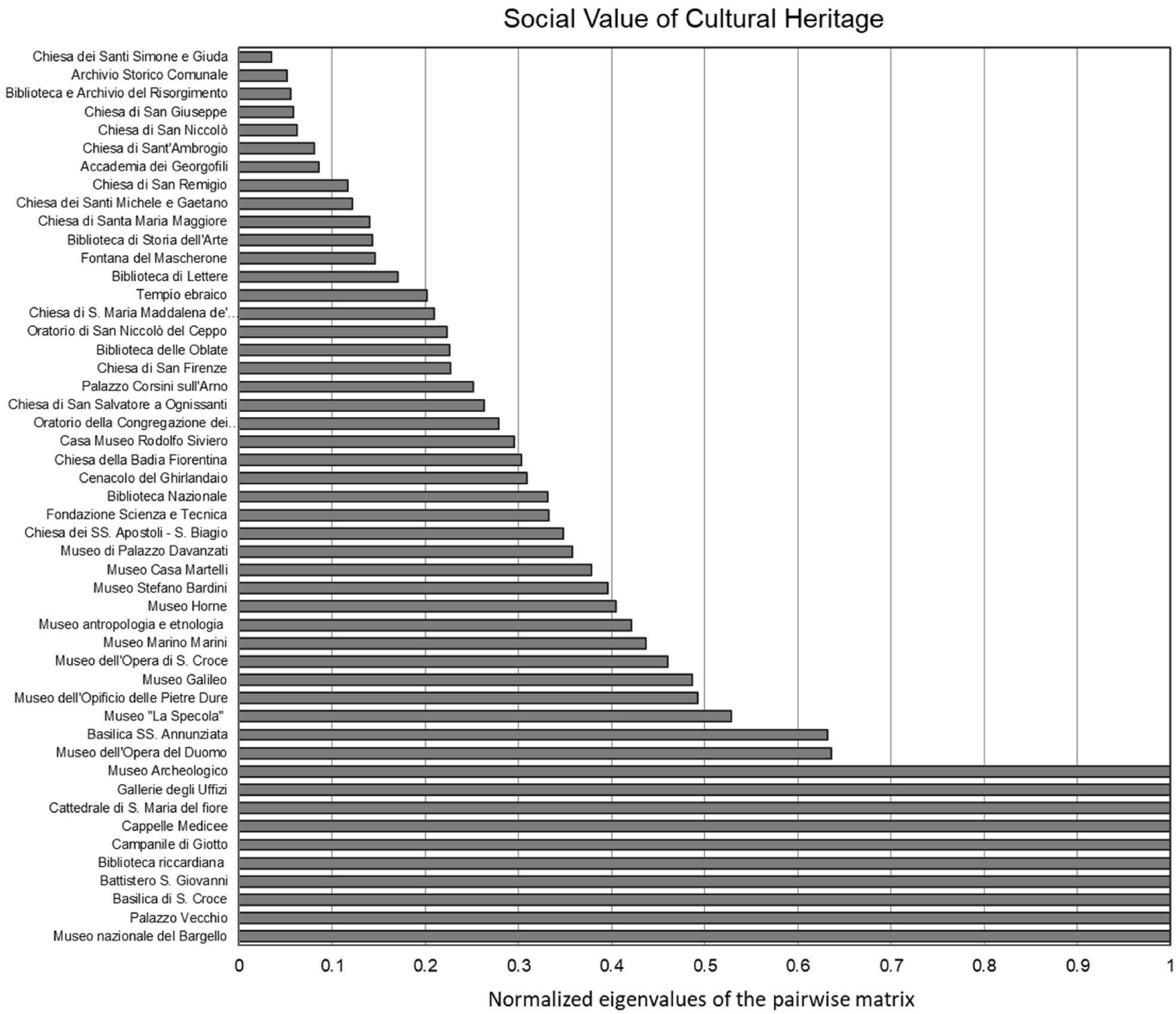

Fig. 3. Social value of cultural heritage buildings obtained from the participatory approach.

In order to assess exposure and vulnerability to floodings, all the managers of cultural heritage within the UNESCO perimeter have been invited to provide key information for the overall risk analysis, for a total number of 48 cultural heritage buildings included in the evaluation of the social value. These buildings include 21 museums, 20 churches and religious buildings and 7 libraries. The pairwise comparison survey was conducted during a workshop in May 2024 where the participants joined both online and in presence. The 57 participants were citizens of Florence identified as a community of interest, defined not necessarily by geographic proximity but by a shared common interest. In our study, the community was sharing the same interest for cultural heritage valorisation being the participants members/volunteers of 43 local cultural associations actively proposing projects within the UNESCO site management plan. Among the participants 55% were women and only a limited percentage had specific expertise on history or art disciplines. During the workshop, the members of the UNESCO office and the participants agreed that cultural heritage buildings classified as OUV had a clear outstanding value for mankind. Therefore, in the survey only one OUV building was kept for evaluating its relative position with respect to the other heritage buildings.

The quantitative metrics for correlation analysis were: the number of visitors in 2019 (the last available official data before the pandemic), the ticket price (based on websites of each heritage building), the surface area as calculated by the digital technical cartography of the Tuscany Region (https://www502.regione.toscana.it/geoscopio/cartoteca.html), and the calculated distance from the centroid of the UNESCO perimeter. The name of the cultural heritage building was used to determine the status of museum or place of worship.

3. Results and discussion

During the workshop, a total of 2379 answers were recorded in the pairwise comparison survey. This number of answers is more than the twice the number of combination of pairs N. As we have 48 cultural heritage buildings the number of combinations is 1128. The answers were elaborated to construct the pairwise matrix and calculate the eigenvalues. The results of the social value analysis are shown in Fig. 3 with ascending order for the 48 heritage buildings analysed. The ten OUV cultural building were assigned the reference value of 1.0 (bottom of figure) which was, as a confirmation, obtained by the only one OUV included in the questionnaire. The scores (eigenvalues) of the other items were scaled relative to the OUV, which was used as reference. The first two buildings after OUV in the ranking are a museum and a church with a value of about 0.65, thus their estimated social value is approximately more than half of OUV heritage buildings. Then the decrease in social value is more uniform up to the last heritage building, again a church, with a value of 0.03, i.e., almost 1/30 of the value of OUV. The social value of cultural heritage building is thus spanning two orders of magnitude. It should be noticed that the buildings are all included into the Ministry of Culture database and as such, within the large-scale studies which consider the level of listing as a proxy of the cultural value, these buildings would have been assigned the same value. For the study area, the median of the social value of nationally listed building is 1/4 of the OUV social value. With respect to works which

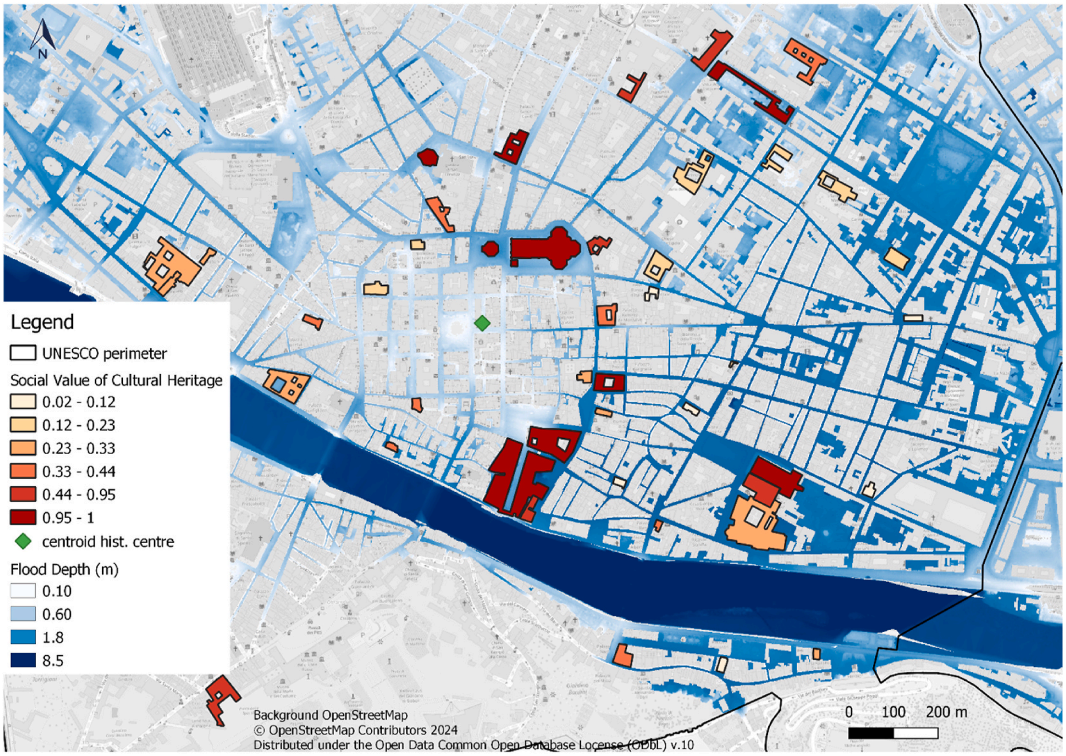

Fig. 4. Map of social value of cultural heritage and flood depth for the historical 1966 flood.

attribute different exposure values depending on the level of listing, the spread between national and UNESCO listing appears different. In fact, in the work by Arrighi et al. [11], the exposure value of UNESCO world heritage has been assumed 20 times the value of nationally listed heritage, and 40 times the local interest heritage. In the work by Figueiredo et al. [12] exposure value of UNESCO heritage has been assumed 1.3 times larger than nationally listed heritage and 4 times larger than the municipal interest heritage. These ratios between social values of UNESCO (OUV), nationally listed and locally listed reflect only one of the components of the multiple intangible values of cultural heritage. However, they can provide an order of magnitude in relative terms, to distinguish between CH values for large scales application where participatory approaches are more difficult to apply.

Besides the scores obtained through the participatory approach, it is possible to notice that after the cultural heritage buildings classified as OUV (10 buildings), the next ten buildings in the ranking are 9 museums and one religious building. The last 10 buildings in the ranking include 7 churches, two archives/libraries and one academy. Thus, although in the study area museums and places of worship are nearly equal in number (21 and 20 respectively), museums are attributed a significantly larger social value.

The map of Fig. 4 shows the map of the social value of cultural heritage buildings in the centre of the UNESCO perimeter and the water depths of the historical 1966 flood.

Fig. 4 also shows the centroid (green diamond symbol) of the most ancient part of the historical city centre, used for the following elaborations, which coincides with UNESCO area. The map reveals that buildings with the highest social value, according to the survey, are not necessarily located in the oldest part of the historical city centre. Additionally, it is evident that the heritage buildings with the highest social value tend to have relatively large footprints.

The correlation analysis aims to highlight possible relationships between the variables, as shown in Table 1. The considered variables are: (1) the surface area of the cultural heritage building, (2) the number of annual visitors, (3) the price of the ticket, (4) being a place of worship, (5) being a museum, and (6) the distance of the building from the centroid of the historic centre. In the study area, 20 out of 48 heritage buildings are places of worship, and 21 are museums. The social value of the heritage building shows the largest Spearman's correlation with the price of the admittance ticket ($r = 0.68$) (Table 1, lower triangle); however, many religious buildings in the study area offer free entrance. Other positive Spearman's correlations are found between social value and being a museum ($r = 0.54$), number of visitors ($r = 0.50$), and footprint area ($r = 0.43$). A small negative correlation is found with the distance from the centroid of the historical centre ($r = -0.35$). The social value is not statistically correlated with the fact of being a place of worship (p-value = 0.06). This does not necessarily imply that places of worship do not contribute to the value of cultural heritage, but rather that they do not significantly contribute to social value intended as the value generated collectively within a community of individuals as a result of person's upbringing, life experience etc. [27]. Their importance is clearly more related to spiritual values that could be further investigated.

The number of visitors shows a positive Spearman's correlation with the area of the building ($r = 0.63$) and price of the ticket ($r = 0.32$) and a small negative correlation with the distance ($r = -0.35$), i.e., the number of visitors tends to decrease when moving outside of the most historical portion of the city centre. There is a high negative correlation between being a museum and being a place of worship, i.e., being a museum excludes being a place of worship. Pearson's linear correlation analysis (Table 1, upper triangle) is very similar to the Spearman analysis. The social value of the heritage building shows the largest Pearson's correlation with the price of the admittance ticket ($r = 0.65$) and with the number of visitors ($r = 0.53$) and being a museum (0.51).

In order to better understand the correlation among variables, the canonical correlation analysis is performed considering the social value as the first variable (Y) and a combination of area, visitors, ticket price, museum and distance as the second variable (X). All variables are normalized according to Eq. (3) (Z-score normalization). The place of worship variable is removed from the analysis since is not statistically correlated with the social value (Table 1). The results are shown in Table 2, which defines the canonical variables U and V (being V trivial as a scalar). The social value appears statistically correlated with two main variables, i.e., the price of the ticket and being a museum, with similar values of the coefficients in A; footprint area and number of visitors become less important, as they are already correlated with the price of the ticket. These results highlight that the variance of the social value of cultural heritage can be

Table 1
Spearman's rank correlation (lower triangle) and Pearson's linear correlation (upper triangle) between social value and other proxies. Missing values correspond to non-statistically significant correlations.

Pearson's / Spearman's	1. Area	2. Number of Visitors	3. Ticket price	4. Place of worship	5. Museum	6. Distance	7. Social value
1. Area	1.00	0.63	0.28				0.41
2. Number of Visitors	0.30	1.00	0.62			-0.30	0.53
3. Ticket price		0.32	1.00	-0.29	0.51		**0.65**
4. Place of worship	-0.38		-0.35	1.00	-0.75		
5. Museum	0.30		0.59	-0.75	1.00		0.51
6. Distance		-0.37				1.00	-0.30
7. Social value	0.43	0.50	**0.68**		0.54	-0.35	1

explained by the price of the ticket (already correlated with the number of visitors) and by being a museum, i.e., already simply correlated with the area. The scatter plot of social value and variables 2, 3 and 5 of Table 1 are shown in Fig. 5 (panels a, b, c). Panel d of Fig. 5 also shows the plot of the two canonical variables U and V which have a better correlation (r = 0.75) with respect to the original single variables. Nevertheless, although the canonical variables U, V are better correlated with each other than the simple variables, an r-value of 0.75 is not very high and demonstrates that the social value is not fully captured through simple quantitative information, such as geospatial characteristics (surface area, distance from the centroid) or socio-economic characteristics (ticket price and number of visitors).

Therefore, the social values depend on the above but also on some other intangible characteristics which might depend on the context, on the background of the involved participants and might also evolve with time. Based on the outcomes of the pairwise comparison survey, highest social values have been attributed to cultural heritage which shapes and narrate the distinct character of the city. Examples are the museums describing local historical personalities and artists or local skills such as the Galileo Galilei Museum, the Opificio delle pietre dure Museum (showcasing the artistic manufacture characterized by the working of semi-precious stones, which was officially founded in 1588 by Ferdinand I de' Medici), the Marini Museum (local sculptor of XX century) and the Specola Museum (one of the most ancient scientific museums in Europe opening to public in 1775).

Fig. 6 compares the standard exposure analysis (panel a), the analysis of physical vulnerability of cultural heritage in terms of water depth for the historical 1966 flood (panel b) and the social impact (panel c) obtained by weighting flood depth with the social value obtained by the participatory approach (Eq. (4)). The panels have a colour scale based on five quantiles of the distribution of values. If only the standard physical exposure is considered (panel a), as it is usually done when the value of cultural heritage is not assessed, only one building (in white color) is not exposed to the flood event. If we consider the potential damage due to the flood magnitude the most impacted buildings are those in dark blue, located in the area close to the river. However, when social value is also taken into account (panel c), the spatial distribution of the most impacted cultural buildings enlarges northward of the study area, away from the river, and shifts towards heritage buildings that, despite having a lower flood depth, possess higher social value.

With respect to other studies related to the risk and potential impacts of natural hazards on cultural heritage, this research addresses the topic of intangible impacts, focusing on the social value of cultural heritage. In many cases, research focuses on the characterization of hazards or physical vulnerabilities [16,17,64,67]. In other instances, cultural heritage values are considered for a single item rather than multiple items in heritage-rich areas [20]. The level of listing has frequently been used in the literature to assign scores or grades to cultural heritage and quantify exposure. This approach is appropriate for exposure analyses conducted at large spatial scales, such as national or regional levels [11,12,68].

At urban or historic city-center scales, the level of listing can help distinguish between UNESCO-listed or nationally designated cultural heritage. However, while this may be suitable for heritage classified as having Outstanding Universal Value (OUV), in many contexts and historic city centers, this approach often assigns equal value to all heritage elements. A participatory approach, by contrast, is better suited for evaluating social value at the community level, as it highlights how the perception of heritage is linked to original features and the identity of the place.

The application of this approach to Florence reveals that museums are perceived as more socially valuable than religious buildings. Moreover, the community assigned higher values to buildings that tell the story of local people, skills, traditions, and crafts. While pairwise comparison is a quantitative method to discern the social value of cultural heritage, the outcomes of the survey reflect the beliefs, opinions, and socio-economic contexts of the participating citizens. Social values, therefore, may vary over time and in response to socio-economic changes.

An additional area for future investigation is whether social value differs among younger, adult, and elderly generations [42]. This aspect was not addressed in the present research, as the focus was on understanding whether including the social dimension could alter risk hotspots and whether simpler proxies could be used to predict social value. We acknowledge that individual characteristics, such as stakeholder group, age, origin, sense of place, and socioeconomic constraints, can all influence how a person perceives the social value of cultural heritage. However, rather than attempting to pre-define and weight these factors, an approach which would require prior assumptions and potentially introduce arbitrariness, the strength of the pairwise comparison method lies precisely in its ability to avoid such biases. In this way, the method captures the diversity of subjective perceptions while maintaining a transparent, reproducible, and unbiased process. While it is true that social value is inherently subjective and influenced by many contextual factors, the pairwise comparison method offers a robust framework for quantifying these subjective preferences without privileging any group in advance. This aligns with the goal of inclusively assessing social value while maintaining methodological rigor. One limitation of this study is the selection of only one intangible value, among the many attributes ascribed to heritage. However, in the authors' opinion, historical, probing, or aesthetic values are better assessed by experts rather than by citizens. Similarly, spiritual value may be considered more of an individual attribute than a communal one.

In conclusion, combining physical and social dimensions in the analysis of intangible impacts reveals that community involvement is key in risk prioritization, as social value often shifts the most at-risk hotspots away from river areas. Furthermore, correlation analysis shows that the social value of cultural heritage is not sufficiently aligned with objective quantitative measures. Thus, the

Table 2
Canonical correlation coefficients (r = 0.75).

	1. Area	2. Number of visitors	3. Ticket price	4. Museum	5. Distance	6. Social Value
A coefficient of U	0.27	0.13	**0.44**	**0.39**	−0.28	
B coefficient of V						1.0

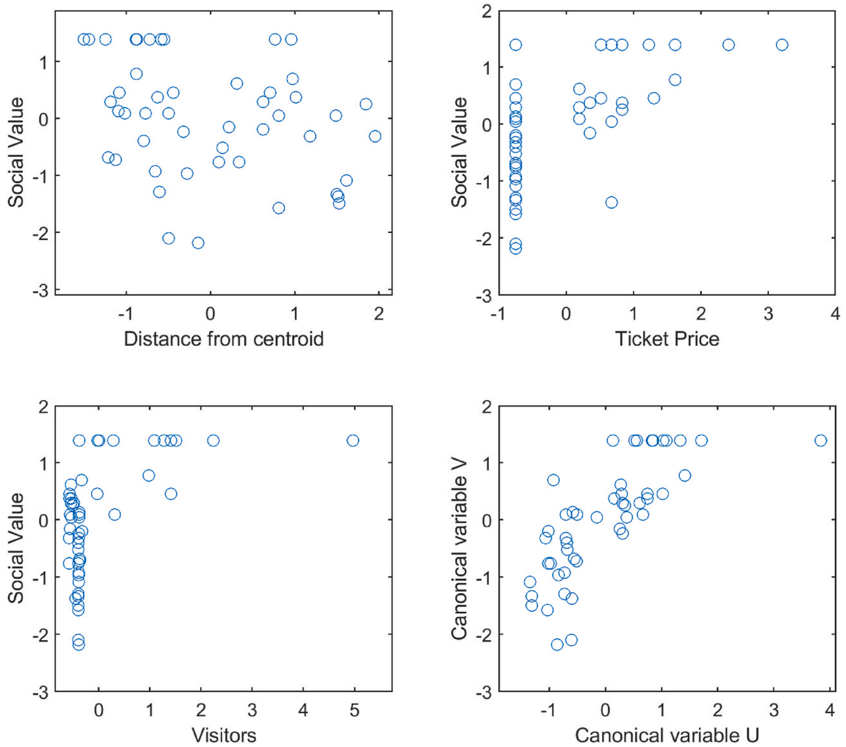

Fig. 5. Scatter plots of Z-score normalized social value and distance from the centroid (a), price of the ticket (b), number of visitors (c) and of the canonical correlation transformed variables (d).

involvement of the community is essential for evaluating exposed elements with intangible values. This approach has the potential to be replicated in other case studies and applied to different types of hazards (e.g., earthquakes, landslides, etc.) and exposed elements with intangible values, such as the environment. Combining social and physical dimensions can help address community needs and involve citizens in risk-informed decision-making.

4. Conclusions

Evaluating potential adverse consequences of natural hazards is a key component of risk management. Exposed values are usually intended as monetary values, such as market values and reconstruction costs of residential buildings or length of infrastructures affected. For cultural heritage, the multi-faceted values encompassing social, aesthetic, spiritual, historical, socio-economic values among others, make impact assessment challenging.

In this work, a participatory yet quantitative approach has been developed to evaluate the social value of cultural heritage buildings in the art city of Florence and to understand if it is linked to simpler proxies, e.g., the number of visitors. Social value is used to calculate intangible impact to the community due to cultural heritage exposure to floods.

The main results of the work are summarized below.

- The pairwise comparison survey provides insights into the community's perception of the social value of cultural heritage at a city scale and serves as a useful, replicable tool for assessing the social value and intangible social impact.
- A significantly larger social value is attributed to the museums with respect to places of worship. Particularly, heritage related to local artistic traditions or personalities shapes the community identity and social values. Ratios between UNESCO heritage and nationally listed heritage is of the order of 4:1 (up to 30:1 for the least important heritage building in the ranking).
- Social value is correlated, with decreasing importance, to the price of the ticket (Spearman's $r = 0.68$), the number of visitors, the fact of being a museum, the surface area of the building and the distance from the centroid (Spearman's $r = -0.35$). Being a place of worship does not appear as a significant factor contributing to social value, probably because spiritual value is perceived as an individual value standing beside the social one.
- The canonical correlation analysis yields a better correlation between social value and a linear combination of the tested variables ($r = 0.75$). The most significant variables are the price of the ticket (already well correlated to the number of visitors) and being a museum.
- The intangible impact obtained by weighting the flood depths with the social value of cultural heritage reveals a different spatial distribution compared to the flood depth map alone, shifting the most at risk area further from the river. This highlights the

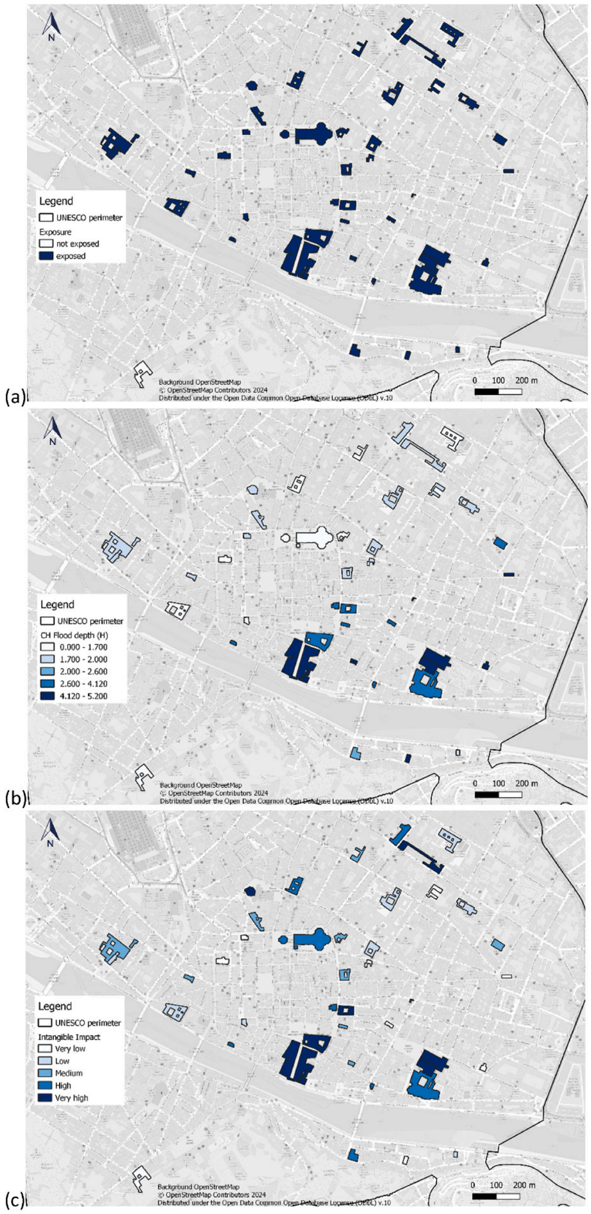

Fig. 6. Standard exposure (a), flood magnitude (b), intangible social impact (c).

importance of considering intangible aspects of cultural heritage values in risk management and prioritization of mitigation measures.

- The methodology developed and tested in the present study have proven to be able to include in a quantitative analysis also those aspects of social value that, not being sufficiently correlated with objective quantitative measures, are largely subjective and can be only explored through direct community participation.

The main limitation of the work is related to possible biases of the involved community. With a pairwise comparison survey the results could change in time due to changes in perception or even change with the type of community involved. In this project the citizens involved can be defined as a community of interest being the participants members/volunteers of 43 cultural associations actively proposing projects within the UNESCO site management plan. With respect to common citizens they have a special attention to cultural heritage. However, with respect to unstructured participation, the pairwise method allows each participant to express his opinion, rather than agreeing on what the majority perceives, this makes the participation more transparent and equitable.

Further research could better understand the sensitivity of the results with respect to a different community, e.g. common citizens (community of place), tourists or young citizens vs elderly. Moreover, it would be interesting to investigate other cultural values such as aesthetic or spiritual ones.

CRediT authorship contribution statement

Chiara Arrighi: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Matteo Masi:** Software, Formal analysis. **Claudia De Lucia:** Data curation. **Fabio Castelli:** Supervision, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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