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Case study

The ResCult project: Implementation of the risk analysis interface for the Church of Santa Maria dei Miracoli and the Covent of San Nicola (Italy)

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ABSTRACT

The present article illustrates the application of the Risk Analysis Interface (RAI), which was developed within the European project ResCult. This assessment model is focused on the risk evaluation of immovable cultural assets and their different components, that need to be preserved and managed in case of extreme events. In detail, this article describes the application of this risk assessment model to the two selected pilot case studies of the project, the Church of Santa Maria dei Miracoli in Venice and the Convent of San Nicola in Tolentino (Italy). This article highlights the application procedure and the results obtained by its implementation in the two pilot case studies. The focus of this article is underlying and explaining in-depth the functioning of the specific evaluation tools, to underline their suitability to be applied in ex-ante, in-itinere, and ex-post phase of a disaster occurrence. The outcome of this article is providing information about how applying the RAI developed within the ResCult project.

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1. Introduction

The current context is presenting a worrying scenario where Cultural Heritage (CH) is increasingly exposed to the uncertainty of natural hazards, such as floods, earthquakes, fires, or extreme weather events [1], due also to the worsening of the climate emergency impact. New tools and methods to assess the degree of vulnerability of cultural unmovable assets are even more needed by Decision Makers (DMs) to support strategy design.

As climate change and the increase in extreme events are growing the attention to assessing the CH risk and its vulnerability [2] many methodologies are available today [3–12] and inspired by the international community [13,14]. However, there is a gap in the literature on the risk assessment of unmovable CH, and no all-encompassing and standardised protocols to assess the risk exposure of unmovable cultural assets have been suggested yet [14–18]. Indeed, each cultural asset has both qualifying and structural features. In this context, the ResCult project developed a Risk Analysis Interface (RAI) to assess the risk of immovable cultural assets, supporting the creation of an interoperable database platform finalised to share information, create protocols, and disseminate best practices in accordance with European policies and standards [14]. According to the relevance of this topic, Appendix A provides a brief literature review describing and comparing the most relevant existing risk assessment frameworks for unmovable cultural assets.

1.1. Research aim

This work illustrates the application of the RAI developed within the ResCult project [19,20]. In detail, this is a case study article that deals with the application of the RAI to two ResCult pilot case studies and on the results obtained according to their characteristics and location [21], the Church of Santa Maria dei Miracoli in Venice and the Convent of San Nicola in Tolentino (Italy). They

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were selected to demonstrate the suitability of the RAI to be applied in different contexts, to support DMs, technicians, and emergency operators in the prevention and mitigation of the effects of a disaster on Cultural Heritage (CH). The RAI combines risk indicators, factsheets, and a multicriteria ranking method into an integrated methodology [22]. Hence, the article focuses on the functioning and suitability of these tools in ex-ante, in-itinere, and ex-post phases of a disaster. The outcome of this research work is to demonstrate the interface reliability in aiding DMs, such as public bodies in CH conservation and management, while increasing the resilience of immovable assets.

2. Methodology and resources

This section provides a general overview of the RAI as a methodology to respond to the current cultural assets demand and then focuses on the individual evaluation tools: the Asset Risk Evaluation Cards (AREC), the questionnaire, the factsheets, and the Operational Dashboard of Evaluation (ODE).

Since one of the main goals of ResCult was to create a common, interoperable, and spatial database at the EU level for Disaster Risk Management (DRM) related to CH, the RAI conformed to the same standard data structures as the entire European Interoperable Database interface (EID).

The database provided adequate documentation and information storage to increase the EU knowledge and communication to protect, valorise, and manage CH, including 3D models, archives, historical data, data collection through the help of stakeholders (i.e. firefighters and Civil Protection). The gathered information favoured to set the ResCult indicators linked to specific risks, by matching and refining results using GIS assessment tools (for more details on this methodology, please see [22]).

2.1. Introduction to the risk analysis interface

This RAI [22,23] aims to assess the state of CH unmovable assets concerning fire, flood, and earthquake risks and considers the following factors:

$$Risk_{CH} = f\left(P_{CH},\ Vu_{CH},Val_{CH}\right) \quad (1)$$

where:

- P_{CH} describes the occurrence probability of a phenomenon in a certain area, with a given return time and a maximum expected intensity;
- Vu_{CH} stands for the cultural asset vulnerability related to one or more risks;
- Val_{CH} refers to the cultural, economic, and social values that a cultural asset can express.

The P_{CH} is the hazard closely related to both territorial and local characteristics of the context in which the cultural asset is located. Vulnerability Vu_{CH}measures the intrinsic features of the asset that make it susceptible to the damaging effects of a hazard. This factor is composed by the following parameters: (1) the structural vulnerability (Vu_{str}) as the ability to maintain the static properties, (2) the functional vulnerability(Vu_{fun}) which stands for the capability to conserve the user functions and (3) the formal vulnerability (Vu_{for}) as the shape characteristics of the building. It should be noticed that the authors replaced the factor of exposure (E) with the value(Val_{CH}), since ResCult was centered on historic buildings rather than, for example, population of an urban territory vulnerable to calamity events. Therefore, Val_{CH} is associated to the relevance of the site and to the "quality" of the cultural asset under investigation.

Fig. 1 illustrates the general functioning of the RAI and related tools to assess the CH state in relation to risk: the "Asset Risk Evaluation Cards" (AREC Cards), the Factsheets, and the Operational Dashboard of Evaluation (ODE) [22] (Fig. 1). These tools were developed to be usable by public bodies, technicians and other specialists for the CH risk assessment. The experts filled in a questionnaire finalised to investigate the relevance of the different elements for the evaluation, concerning the examined risks. A synthetic index for each type of risk was determined as result of the integration of the tools' outputs in the ODE. The risk index is a non-dimensional value included in the interval [0, 1], where an index near to zero means that the cultural asset is at low risk, whereas an index near to 1 denotes a high risk [22]. Therefore, this index measures the state of CH assets according to the risk exposure.

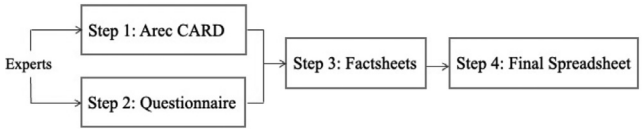

Fig. 1. General framework of the RAI interface.

2.2. Step 1: AREC Cards

The ResCult project's AREC Cards [20,22] describe the characterization of the unmovable asset, through risk parameters, which include the site characteristics (P_{CH}), the formal, functional, and structural aspects of the building (Vu_{CH}) and components (or indicators) aimed to measuring specific characteristics of hazard and vulnerability related to the cultural asset. They can be assessed separately for priority categorization and also be aggregated into composite indices [14]. Tables from B.1 to B.3 of Appendix B list the set of parameters and components for fire, flood, and earthquake risks.

2.3. Step 2: questionnaire

The relevance of parameters and components for the computation of the risk indices was assessed in a survey through a questionnaire duringone of the two ResCult User Forums [17] with the participation of the project's partners, national and international experts. In the First User Forum (November 27th 2017, Venice), the questionnaire was filled out by a panel of 19 experts (please see the article [22], p. 273 for the panel composition). The Simple Multi-Attribute Rating Technique Extended to Ranking (SMARTER), a type of Multicriteria Decision Analysis (MCDA) [24–26] was retained suitable to rank the importance of parameters and components of each risk, elicit their weights and determine the final priorities (i.e. overall weights, GL_{iN}) [22,23]. The SMARTER results were then employed in step 4 of the process (Fig. 1). The set of weights obtained through SMARTER are reported in Appendix C.

2.4. Step 3: Factsheets

The Factsheets are the third tool to support operationally the evaluation process [22]. They were implemented to gather data and information, taking into account the AREC parameters and components, and evaluate the conditions of hazards and vulnerability of the cultural assets. The total Factsheets are 46 and each one corresponds to an AREC Cards component[1][23]. Experts evaluated the real conditions of components of the examined assets by using a semi-qualitative scale. The evaluations were converted from qualitative classes into numerical values, which are divided with five as the total scores for obtaining the normalized values (Table 1)(please see [22] p. 271). This score is then divided with 5

[1] Parameters: vulnerability and hazard; Components: risk indicators

Table 1
Factsheets'evaluation approach (example of fire factsheets evaluation).

Risk: Fire			
Parameter: Local hazard Component: Conditions of the architectural and urban context			
Component attributes	Qualitative classes	Numerical values	Normalized values (NV_i)
High building density, very small distances between buildings. Very hard accessibility	Very high	5	1
High building density, very small distances between buildings. Hard accessibility (eg medieval city)	High	4	0.8
Medium building density, reduced distances between buildings. Medium accessibility. (eg Renaissance or Modern city)	Medium	3	0.6
Low building density, large distances between buildings. Easy accessibility. (eg Contemporary city)	Low	2	0.4
Very low building density, large distances between buildings, isolated buildings. Easy accessibility.	Very low	1	0.2

as the total number of scores to obtain a Normalized Value (NV) equal to 0.4). In the Second User Forum (April 11th 2018, Venice), a second specialists' panel filled the Factsheets of Santa Maria dei Miracoli Church, with expertise in conservation of CH, risk management, engineering, and planning evaluation. The experts evaluation were supported by a variety of information sources, such as cartographic data (i.e. blueprints, sections, and elevations), on-site surveys, and inspections, to deliver a comprehensive overview of the state of both cultural assets (For more see [14], pp. 9–16). The factsheets about San Nicola in Tolentino were filled through a precautionary desktop approach, due to the 2016 earthquake damages and for the consequent activation of securing interventions, which are still ongoing and waiting for recovery measures.

2.5. Operational dashboard of evaluation

The last step of the RAI is performed through an Operational Dashboard of Evaluation (ODE), an Excel spreadsheet that combines Factsheets and SMARTER evaluations (please see [22], p. 273). A final index was calculated for each risk by aggregating the Global Values (GV_i) by SMARTER and the Normalized Values (NV_i) by Factsheets. However, the ODE can also visualize partial results by normalizing local weights of groups of components belonging to specific parameters (Eq. (3)). The ODE is dynamic since those components considered irrelevant by the panel can be excluded from the evaluation without compromising the final index calculation. The ODE includes a second sheet hypothesizing the riskiest scenario where all the Factsheets values are maximised, and the final index reaches the unity. Hence, a ratio index (R_z) between the original index (R_i) (Eq. (4)) and the maximum scenario index (R_i^{max}) can be obtained (Eq. (5)) to verify the sensitivity of the risk index. Please see the ODE structure and the two applications in Appendices C and D.

$$GL_{iN} = LW_{iN} \times GW_{iN}, \tag{2}$$

$$LW_{iN} = \frac{LW_i}{max_{i=1}^{m} LW_i}, \quad GW_{iN} = \frac{GW_j}{max_{j=1}^{n} GW_j} \tag{3}$$

$$R_i = \sum_{i=1}^{N} GV_i = GL_{iN} \times NV_i \tag{4}$$

$$R_z = R_i / R_i^{max} \tag{5}$$

2.6. Pilot study cases

The RAI was applied to two study cases of the ResCult project, the Church of Santa Maria dei Miracoli in Venice, and the Convent of San Nicola in Macerata Province (Italy). The ResCult project identified two important cultural assets characterized by different locations, hazards, climate and weather conditions, and construction elements [23], and interested by the occurrence of one or more disasters [14]. Analogously, the above-mentioned motivations are crucial to test the RAI applicability.

2.7. Church of Santa Maria dei Miracoli (Venice, Italy)

The Santa Maria dei Miracoli Church is located in the historic center of Venice, in the Cannaregio district, between the Rialto Bridge and San Marco's square (Fig. 2). The church is one of the very first Renaissance-style buildings in Venice. The interior and exterior of the church are completely covered in polychrome marble (veined Tuscan *pavonazzetto*, Istrian stone, serpentine) which is a distinguishing characteristic of high artistic value [27,28]. This church was retained suitable for the RAI application, given its historic-ecclesiastical relevance, the degree of vulnerability to flooding events and high-water events in the Venice lagoon, but also to fires, and earthquakes. Drawings from the regional technical blueprint by the Veneto geo-catalog served as spatial data for the evaluation.

2.8. Convent of San Nicola (Tolentino, Italy)

The complex of the Convent of San Nicola, a crucial cultural site, is located in the historical center of Tolentino (Fig. 3), in Marche Region. This central-eastern part of Italy is classified in the seismic zone 2 with a medium-high exposure to earthquakes [29].

Four main architectural elements constitute the Convent of San Nicola: (1) the cloister (Fig. 3), that were constructed and modified in different historical periods, (2) the church, (3) the bell tower, and (4) the sacristy, constructed in the '600. The organization of these architectonic components follows a regular, symmetrical, and proportionate morphology. Nonetheless, this was not sufficient to limit the damages caused by the 2016 earthquake. In accordance with the historical period of construction, the various components are also distinguished by various building materials, such as a stone portal in the church's façade, and stone and wooden ceilings inside the church. Thus, the combination of several materials with different structural properties, the critical conditions of the structural connections, and the disproportioned height expose the Convent to a higher level of risk. The main data employed are the 3D model, Digital Terrain Model (DTM), and regional technical blueprint by the Marche geo-catalog.

3. Results

Fig. 4 compares the results obtained by the RAI's application to Santa Maria dei Miracoli Church and Convent of San Nicola.[2]

[2] The evaluation of the Convent of San Nicola was developed in a precautionary way, due to the recovery intervention that prevent the access to the cultural asset. Thus, the calculated risk indices are very high in the three risk categories.

Fig. 2. Localization of the Church of Santa Maria dei Miracoli (Elaboration from Google Earth data, 2020) and its façade (Beniculturali online https://www.beniculturalionline.it/location-3609_Chiesa-di-Santa-Maria-dei-Miracoli.php).

Fig. 3. Territorial framework of the Convent of San Nicola(Elaboration on Google Earth data) and the cloister (Centro Studi Agostino Trapé, 2008).

The final output is the calculation of risk indexes of fire, flood, and earthquake, that considers hazards and vulnerabilities into an overall assessment. These indexes are obtained by integrating the outputs of the factsheets and SMARTER within the ODE (see Appendices C and D).

The Church of Santa Maria dei Miracoli recorded an index of highest fire risk (66.73%), followed by the earthquake (62.93%), and flood (56%) indices (Fig. 4a). These results are due to the high vulnerability of the church materials to fires and the lack of a fire-prevention system. Indeed, a fire event could cause damages such as in structural aspects, or loss of objects of cultural values, among others. The components “Staff for emergency prevention” and “Type structure of the building” highlight well this issue with their relevance (13.63% and 9.79%), whereas the “Distribution type” is the least important (0.66%). The wooden coffered ceiling, the loft structure in the organ area, the wooden structure of the vault itself, and the kneelers in the nave are highly exposed to fire hazards. Fire occurrence could destroy the vault’s roof and cause the consequent collapse of the roof, whereas the vertical wall structures could not suffer structural damages, but rather minor entities (e.g., blackening). Concerning flood hazard, the riskiest components are “Contrast of risk” (15.59%), “Geomorphological conditions” (9.59%) and the “Functional typology” (6.52%), whereas the “Distribution type” is again the least relevant component (1.15%). The church is not equipped with "high water" waterproofing systems. There are no sub-basins or electro-hydraulic drainage systems (e.g. emptying pumps). The paving of the Church’s nave is placed 50 cm or more above the level of the adjacent streets. This means that it is flooded only by tides (high water) exceptionally, greater than 140–150 cm above the average sea level. The sacristy is placed at a lower level and is therefore flooded with quite normal high tides (greater than 105–110 cm on the l.m.m.). The attention to these features could implement interventions for limiting damages during intense events, such as the one in November 2019, caused by a sudden formation of a local "cyclonic zone" which increased the wind speed in a short time, and the consequent raising of 30–40 cm of water level. Referring to the earthquake risk, the components “Conditions of architectural and urban contexts” and “Functional typology” are the riskiest (17.78% and 15.26%), whereas the “Stairs” is the less relevant (0.14%) (please, see Appendix D for parameters values). The church is not equipped with anti-seismic systems. The unique anchoring elements are ten chains connecting the side walls of the nave to the height of the eaves, which absorbs the vault’s thrusts. These chains, which provide a contrast to the horizontal component of the thrust, can still be considered partially collaborating in solidarizing side walls and roofing in the

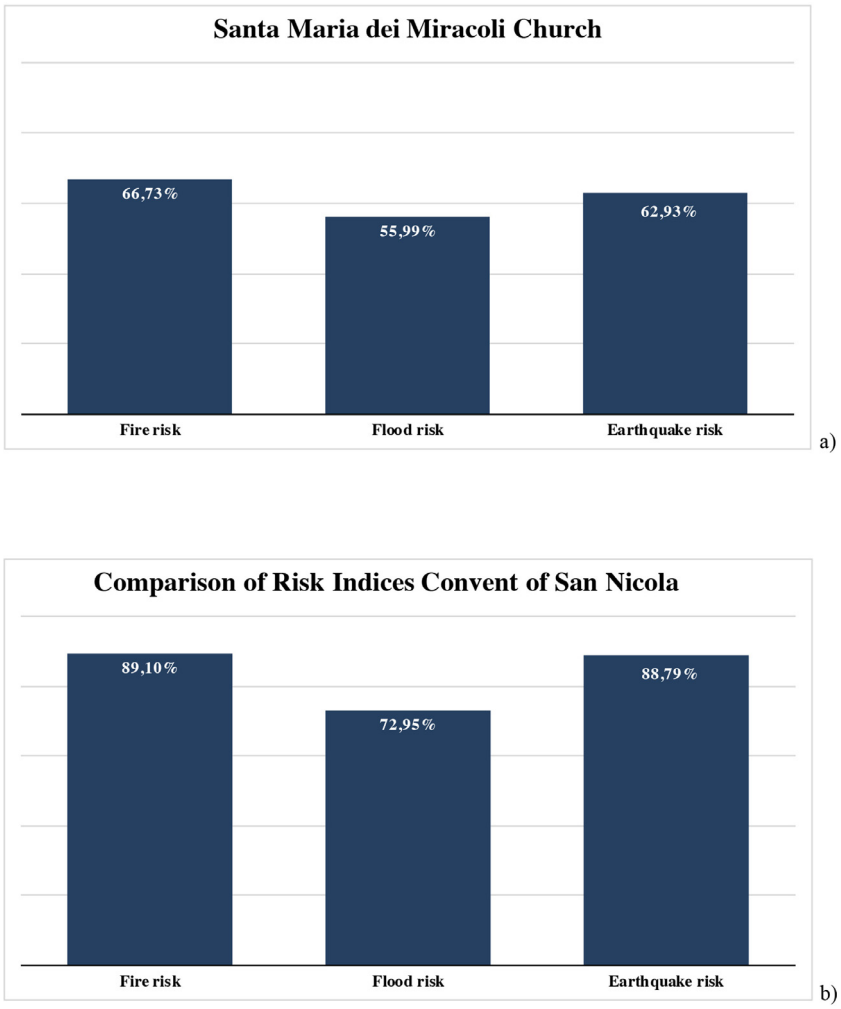

Fig. 4. Comparison of final risk indices for the Santa Maria dei Miracoli Church (top) and the Convent of San Nicola (bottom).

event of a non-seismic event of not high intensity. The structures of the central vault and the dome, however, seem sufficiently integral to avoid detachment of the component elements, always considering medium-low intensity events. No elements of degradation are visible, even if damage within the structures cannot be excluded.

Concerning the Convent of San Nicola, the fire risk is the most relevant (89.10%), followed by earthquake and flood risks. The main fire risk elements are (1) Urban fire prevention systems and (2) Staff for emergency intervention, whereas "Function typology" and "Condition of architectural and urban context" record medium final values (8.68% and 8.31% respectively) (please see Appendix E for all the results). Finally, the least significant element for the fire risk is "Distribution type" (0.99%), due to the asset's regular organization. All global values are summarised in a final risk index equal to 89.10%. For the earthquake risk, a precautionary evaluation was undertaken due to the unavailability of data on the convent complex, after the 2016 earthquake damages. The "Local hazard" and the "Functional typology" are considered the riskiest elements (22.20% and 25.44% respectively). The components "Geological conditions" and "Seismic conditions" are medium relevant (14.92% and 13.37%, respectively). The remaining components are ranged between 1.45% and 0.20%, thus demonstrating minor relevance for the earthquake risk. The earthquake index is 88.79% (Fig. 4b).

The results for fire and earthquake are mainly due to their precautionary evaluation, by assigning the highest value to the elements of hazard and vulnerability. Currently, the architectonic complex is under recovery and is not accessible to visitors. In relation to the flood risk, the complex is not equipped with water protection systems. The most relevant components are "Contrast at risk" (11.59%), "Functional typology" (10.86%), "Structural typology", and "Geomorphological conditions" record similar values equal to 9.70% and 9.59%. The less risky component is "Distribution type" (1.73%).

The flood risk index is the least relevant than the other indices (72.95%) since the Convent is located in an area highly exposed to earthquakes. However, the index is medium-high due to the lack of flood prevention systems. It should be noticed that the obtained results (Fig. 4) are influenced by the set of weights and the site-specific characteristics of both assets (see Appendices C and D). On the one hand, the Factsheets can determine the priorities of intervention, focusing the attention on cultural assets' state and their vulnerabilities. Thus, the suitability of the factsheets can be demonstrated during the disaster occurrence. In fact, operators can identify and report damages and information useful to support decision-makers and technicians to set necessary interventions. On the other hand, the SMARTER method can provide the relevance of the parameters and components of the cultural asset in the *ex-ante* phase.

The RAI and its application in different contexts and scenarios can prove to be a reliable tool for risk assessment of CH. The results have allowed a generalization of the model, and opened to a potential enrichment of the EID platform with additional cultural assets, thus looking for a multi-level collaboration between EU countries, a continuous monitoring, and a sharing collection of best practices for cultural heritage.

4. Discussion and conclusions

This case study article has illustrated the application of the RAI developed in the ResCult project and its results referred to the two pilot case studies [10]. As the whole EID interface, the RAI focused on the assessment of fire, flood, and earthquake risks of the Church of Santa Maria dei Miracoli and of the Convent of San Nicola. As main finding, this double application proved the RAI's suitability to assess hazards and vulnerability of immovable cultural assets, taking into account both such assets' characteristics and their location. The main advantages of the RAI are summarised as follows. First of all, it is considered a promising tool for identifying the state-of-the-art risk exposure of CH assets, defining and prioritizing interventions to increase the resilience of CH [22,23]. Thus, the RAI is a practical tool to be spent at European and national levels. According to the evaluation output as risk index, it can be used as a supporting the formulation of policies for CH prevention, mitigation, and management prior to and after events, according to the different magnitude of risk levels for fire, flood, and earthquake. Secondly, according to the integration of the evaluation results with the EID [14], this tool can be applied in different phases of risk, *ex-ante, in-itinere, and ex-post*. In the *ex-ante* phase of the disaster, the knowledge of hazard and vulnerability derived from spreadsheet compilation and the subsequent risk level evaluation might raise the awareness of the current conditions of the asset itself within the different components and its location, supporting the definition of interventions for an improvement of the conditions of both the building's elements and location features. In the ongoing phase, the RAI [14] could help emergency operators through the EID platform, for example notifying the characteristics of the building and its condition before a risk event, and thus calibrating their action in terms of time and resources following the risk occurrence (e.g. debris removal, or secure objects of cultural value). In the same phase, the RAI could also inform public bodies about the condition of the cultural asset, and support them in the setting of emergency interventions, reconstruction strategies and in the identification of methods for recovery and reconstruction of buildings, depending on the levels of vulnerability and damage incurred during the recovery phase. For example, the expenses for the reconstruction of the most vulnerable parts of a building construction, or the depreciation of the overall value of a cultural asset can be used to estimate the damage through traditional economic appraisal tools [30].

Therefore, it can be stated that the RAI's application can support public bodies, technicians, and emergency operators throughout all stages of a potential disaster and also better understand the benefits of its implementation [31,32].

Furthermore, according to these benefits, the RAI could potentially integrate the factsheets and SMARTER with GIS methods in the *ex-ante* phase, to attribute global values to each element of the asset and its context for the future implementation of the model. A Spatial Multicriteria Decision Support System Approach (MC-SDSS) will be employed to accomplish this. The RAI could assign in the *ex-post phase* specific responses to each component of the cultural asset, depending on the severity of the damage. The RAI application also revealed some drawbacks, because the ResCult project covered only one year, and this research did not continue in a subsequent EU project. It is necessary to conduct a study of the parameters and components of cultural assets to determine their completeness and to verify the weights assigned using the SMARTER approach, with the aid of other evaluation methodologies, and by involving additional specialists to the pool through an additional questionnaire.

As well, the future research perspective should foresee the comparison of the RAI of ResCult project with the most recent risk evaluation frameworks [33–35]. Therefore, the RAI could benefit from the integration of the literature on the economic valuation of public goods and services [36]. Furthermore, the future implementation will integrate the evaluation of the societal, cultural, and economic components of the Total Economic Value (TEV) expressed by the case studies using the Travel Cost Method (TCM), that was developed for the Church of Santa Maria dei Miracoli as a separate evaluation [37,38]. The TCM will be thus employed for Tolentino's Covent to deliver to DMs a comprehensive and comparative assessment of the TEV value of these cultural assets. The unavailability of data is a potential limitation to be taken into account. Even if the choice of a cultural asset was crucial for the ResCult mission, a total or partial data unavailability could impact on how findings will be compared. A further limitation intended as future refinement concerns the SMARTER method. Even if this weighting procedure favours easily the ranking of sets of elements, it does not allow to rank two or more elements as equally relevant. In this circumstance, the authors recommend to minimize the number of components of each parameter, for example by clustering the most similar ones, while still using SMARTER. As an alternative to SMARTER, we will use the Deck Cards Method by Simos, Figueira, and Roy (DCM-SRF) to expand the weighting mechanism beyond the identified limits [39].

The RAI preserves bright prospects for upcoming integrations and improvements in light of the aforementioned benefits and limitations. First of all, some guidelines should be provided to support the score of components according to their state of damage, and level of vulnerability within suggestions and examples. Moreover, To further enhance the RAI outputs, additional integrations will be taken into account, such as the Cost-Benefit Analysis (CBA) [7,22,23,31,32,40–44] to relate risk assessment with the adjustments and constructive interventions and cost optimization, or the Portfolio Decision Analysis (PDA) to support the selection of the most suitable restoration project that optimize objectives without exceeding the available budget [45,46].

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Appendix A. Literature review of risk analysis framework for unmovable cultural heritage assets (update from [47])

*More in detail, it is necessary to underline that this table summarizes the most significative risk assessment framework for unmovable cultural heritage. Authors would like to emphasize that in the literarture many case studies and risk assessment frameworks are referred to artworks [56,57], archeological sites [58]. Moreover, some of the proposed risk assessment framwork concern a large scale of analysis, such as studies proposed by [33,59].

Therefore, according to the different purposes of these risk assessment model, they have not been included in the table of the literature review.

Author	Case study	Objective	Methodology
[48]	A framework for the simplified risk analysis of cultural heritage assets	Evaluating the multi-hazard risk of the Roman Temple of Evora (Portugal)	Qualitative multi-hazard risk analysis. It is a simplified risk assessment framework to be applied as a screening procedure for unmovable cultural assets.
[49]	The environmental risk assessment applied to cultural heritage. A methodological approach.	Evaluation of environmental risk of cultural assets	Vulnerability matrix
[50]	Local site conditions and seismic risk assessment of historic buildings	Assessing the effects of local site conditions on the seismic performance of specific cultural heritage building	Analysis of building response analysis
[51]	Review of vulnerability indicators for fire risk assessment in cultural heritage	A review of existing indicator-based methods for fire risk assessment applicable to build cultural heritage assets.	Analyses existing fire safety guidelines and recommendations dedicated to cultural heritage assets. As an outcome, this study proposes twenty-two vulnerability indicators grouped into four categories that can be used to develop a fire risk assessment method dedicated to build cultural heritage assets.
[52]	A multi-hazard risk prioritization framework for cultural heritage assets	Proposing a multi-hazard risk prioritization framework specifically developed for CH assets.	Multilevel rapid-visual-survey (RVS) form for the multi-hazard exposure
[53]	A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia)	Proposing a new risk assessment index for cultural heritage (Cultural Heritage Risk Index (CHRI))	Indicator-based model and final Risk Index
[54]	Developing a model for building resilience to climate risks for cultural heritage	Proposing a model for developing climate adaptation strategies to reduce climate risk for cultural heritage.	Qualitative assessment through the developed cultural heritage adaptation forum
[55]	Architectural Cultural Heritage Conservation: Fire Risk Assessment of Ancient Vernacular Residences Based on FAHP and EWM	Applying the proposed risk assessment model to the pilot case study of a southern Guangdong He Xinwu building complex	Indicator-based system. Four indicator categories: human factors, facility factors, environmental factors, and social management factors, and 20 sub-indicators to establish an assessment system for fire risk in vernacular residences. The indicators are combined through triangular fuzzy hierarchical analysis and the entropy weight method to determine weight.

Appendix B. Tables of parameter and components considered for the evaluated risks

Table B.1
Table of parameter and components considered for the fire risk.

Parameter	*Component*	*Description*	*Value*	*Component Weight*	*Parameter Weight*
Regional hazard Rig_f	Climatic conditions $^{Rig}f(1)$	Dry climate and high average temperatures	Very high	$^{W}Rig_f(1)$	$^{W}Rig_f$
		Dry climate or high average temperatures	High		
		Temperate climate / normal average temperatures	Medium		
		Wet weather or low average temperatures	Low		
		Wet weather and low average temperatures	Very low		
	Weather conditions $^{Rig}f(2)$	Areas with very low rainfall	Very high	$^{W}Rig_f(2)$	
		Areas with low rainfall	High		
		Areas with medium rainfall	Medium		
		Areas with high rainfall	Low		
		Areas with very high rainfall	Very low		
	Territorial conditions $^{Rig}f(3)$	Presence of very high fire risk elements	Very high	$^{W}Rig_f(3)$	
		Presence of high fire risk elements	High		
		Presence of medium fire risk elements	Medium		
		Presence of low fire risk elements	Low		
		Presence of very low fire risk elements	Very low		
Local hazard Ril_f	Conditions of the architectural -urban context $^{Ril}f(1)$	High building density, very small distances between buildings. Very hard accessibility	Very high	$^{W}Ril_f(1)$	$^{W}Ril_f$
		High building density, very small distances between buildings. Hard accessibility (eg medieval city)	High		
		Medium building density, reduced distances between buildings. Me-dium accessibility. (eg Renaissance or Modern city)	Medium		
		Low building density, large distances between buildings. Easy accessibility. (eg Contemporary city)	Low		
		Very low building density, large distances between buildings, isolated buildings. Easy accessibility.	Very low		
	Urban fire prevention system $^{Ril}f(2)$	Urban fire prevention systems not available	Very high	$^{W}Ri_fl(2)$	
		Urban fire prevention system available, but with low diffusion/efficiency	High		
		Urban fire prevention system available, with low/medium diffusion/efficiency	Medium		
		Urban fire prevention system available, with medium diffusion/efficiency	Low		
		Urban fire prevention system available, with high diffusion/efficiency	Very low		
Vulnerability Vu (form) $^{Vu}f_for$	Distribution type$^{Vu}f_for(1)$	Distributive routes that make evacuation very problematic	Very high	$^{W}Vu\text{-}f_for(1)$	$^{W}Vu\text{-}f_for$
		Distributive routes that make evacuation problematic	High		
		Distributive routes that partially facilitate evacuation	Medium		
		Distributive routes that facilitate evacuation	Low		
		Distributed routes for effective evacuation	Very low		
	Furrnishings, coatings, objects, non-structural elements $^{Vu}f_for(2)$	Elements with very low fire resistance	Very high	$^{W}Vu\text{-}f_for(2)$	
		Elements with low fire resistance	High		
		Elements with medium fire resistance	Medium		
		Elements with high fire resistance	Low		
		Elements with very high fire resistance	Very low		
	Objects of cultural importance contained in the building $^{Vu}f_for(3)$	Totality of objects at risk of fire	Very high	$^{W}Vu\text{-}f_for(3)$	
		High presence of objects at risk of fire	High		
		Medium presence of objects at risk of fire	Medium		
		Low presence of objects at risk of fire	Low		
		No objects at risk of fire	Very low		
	Building fire prevention system $^{Vu}f_for(4)$	System not present	Very high	$^{W}Vu\text{-}f_for(4)$	
		System present but underdeveloped and inefficient	High		
		System present but not efficient	Medium		
		System present of medium efficient	Low		
		System present and efficient	Very low		
	Fire-fighting elements [41] $^{Vu}f_for(5)$	Elements not present	Very high	$^{W}Vu\text{-}f_for(5)$	
		Elements partially present but inefficient	High		
		Elements partially present and partially efficient	Medium		
		Elements partially present and efficient	Low		
		Elements present and efficient	Very low		
Vulnerability Vu (function) $^{Vu}f_fun$	Functional typology Vu f_fun(1)	Public building with very high affluence	Very high	$^{W}Vu\text{-}f_fun(1)$	$^{W}Vu\text{-}f_fun$
		Public building with high affluence	High		
		Public building with medium affluence	Medium		
		Public building with low affluence	Low		
		Private or uninhabited building	Very low		
	Staff for emergency intervention	Absent staff	Very high	$W_{Vu\text{-}f_fun(2)}$	
		Staff almost absent and poorly trained	High		
		Staff partially present and / or not sufficiently trained	Medium		
		Staff partially present and trained	Low		
		Staff present and trained	Very low		
Structural Vulnerability	Type structure of the building	Structural elements with no fire resistance	Very high	-	$W_{Vu\text{-}f_stru}$
		Structural elements with low fire resistance	High		
		Structural elements with medium fire resistance	Medium		
		Structural elements with medium/high fire resistance	Low		
		Structural elements with high fire resistance	Very low		

Table B.2
Table of parameter and components considered for the flood risk (continue).

Parameter	*Component*	*Description*	*Value*	*Component Weight*	*Parameter Weight*
Regional hazard Rig_f	Weather conditions $^{Rig}h(1)$	Very high rainfall area	Very high	$^{W}Rig_h(1)$	$^{W}Rig_h$
		High rainfall area	High		
		Medium rainfall area	Medium		
		Low rainfall area	Low		
		Very low rainfall	Very low		
	Geo- morphological conditions $^{Rig}h(2)$	High proximity to natural or artificial risk elements	Very high	$^{W}Rig_h(2)$	
		Medium/high proximity to natural or artificial risk elements	High		
		Medium proximity to natural or artificial risk elements	Medium		
		Low proximity to natural or artificial risk elements	Low		
		No proximity to natural or artificial risk elements	Very low		
	Regional hydrographic conditions $^{Rig}h(3)$	Main hydrographic network with very low efficiency	Very high	$^{W}Rig_h(3)$	
		Main hydrographic network with low efficiency	High		
		Main hydrographic network with medium efficiency	Medium		
		Main hydrographic network with high efficiency	Low		
		Main hydrographic network with very high efficiency	Very low		
	Global territorial conditions $^{Rig}h(4)$	High ground cover	Very high	$^{W}Rig_h(4)$	
		Medium/high ground cover	High		
		Medium ground cover	Medium		
		Low ground cover	Low		
		Very low ground cover	Very low		
Local hazard Ril_f	Local hydrographic conditions $^{Ril}h(1)$	Secondary hydrographic network with very low efficiency	Very high	$^{W}Ril_f(1)$	$^{W}Ril_h$
		Secondary hydrographic network with low efficiency	High		
		Secondary hydrographic network with medium efficiency	Medium		
		Secondary hydrographic network with high efficiency	Low		
		Secondary hydrographic network with very high efficiency	Very low		
	Contrast of risk $^{Ril}h(2)$	Absence of natural or artificial elements to counteract the risk	Very high	$^{W}Ril_h(2)$	
		Low presence of natural or artificial elements to counteract the risk	High		
		Partial presence of natural or artificial elements to counteract the risk	Medium		
		High presence of natural or artificial elements to counteract the risk	Low		
		Very high presence of natural or artificial elements to counteract the risk	Very low		
	Conditions of the architectural urban context $^{Ril}h(3)$	High building density, very small distances between buildings. Very hard accessibility	Very high	$^{W}Ril_h(3)$	
		High building density, very small distances between buildings. Hard accessibility (eg medieval city)	High		
		Medium building density, reduced distances between buildings. Medium accessibility. (eg Renaissance or Modern city)	Medium		
		Low building density, large distances between buildings. Easy accessibility. (eg Contemporary city)	Low		
		Very low building density, large distances between buildings, isolated buildings. Easy accessibility.	Very low		
Vulnerability Vu (form) $^{Vu}f_for$	Building protection systems $^{Vu}h_for(1)$	Systems not present	Very high	$^{W}Vu\text{-}h_for(1)$	$^{W}Vu\text{-}f_for$
		Low efficiency systems	High		
		Medium efficiency systems	Medium		
		High efficiency systems	Low		
		Very high efficiency systems	Very low		
	Distribution type$^{Vu}f_for(2)$	Distributive routes that make evacuation very problematic	Very high	$^{W}Vu\text{-}f_for(2)$	
		Distributive routes that make evacuation problematic	High		
		Distributive routes that partially facilitate evacuation	Medium		
		Distributive routes that facilitate evacuation	Low		
		Distributed routes for effective evacuation	Very low		
	Furrnishings, coatings, objects, non-structural elements $^{Vu}f_for(3)$	Very high presence of elements exposed to risk	Very high	$^{W}Vu\text{-}f_for(3)$	
		High presence of elements exposed to risk	High		
		Medium presence of elements exposed to risk	Medium		
		Low presence of elements exposed to risk	Low		
		Very low presence of elements exposed to risk	Very low		
Vulnerability Vu (function) $^{Vu}f_fun$	Functional typology Vu f_fun(1)	Public building with very high affluence	Very high	–	$^{W}Vu\text{-}h_fun$
		Public building with high affluence	High		
		Public building with medium affluence	Medium		
		Public building with low affluence	Low		
		Private or uninhabited building	Very low		
Vulnerability Vu (structure) Vu_{h_str}	Structural typology Vu h_stru(1)	Structural elements with very low resistance to flood	Very high	–	$^{W}Vu\text{-}h_stru$
		Structural elements with low resistance to flood	High		
		Structural elements with medium resistance to flood	Medium		
		Structural elements with high resistance to flood	Low		
		Structural elements with very high resistance to flood	Very low		

Table B.3
Table of parameter and components considered for the earthquake risk (continue).

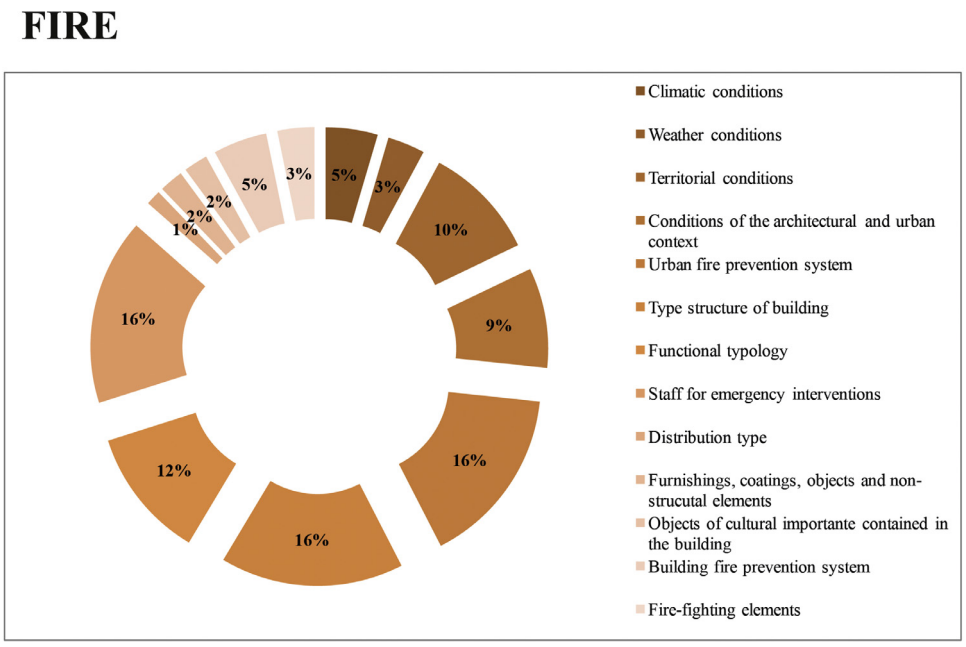
Parameter	Component	Description	Value	Component Weight	Parameter Weight
Regional hazard Rig_e	Seismic conditions $^{Rig}e(1)$	Predicted maximum ground acceleration very high (0.240–0.300 g)[44]	Very high	$^{W}Rig_e(1)$	$^{W}Rig_e$
		Predicted maximum ground acceleration high (0.180–0.240 g)	High		
		Predicted maximum ground acceleration medium (0.120–0.180 g)	Medium		
		Predicted maximum ground acceleration low (0.060–0.120 g)	Low		
		Predicted maximum ground acceleration very low (0–0.060 g)	Very low		
	Geological conditions $^{Rig}e(2)$	Soils with maximum amplification of the phenomenon	Very high	$^{W}Rig_e(2)$	
		Very favorable terrains for the amplification of the phenomenon	High		
		On average favorable terrains for the amplification of the phenomenon	Medium		
		Less favorable terrains for the amplification of the phenomenon	Low		
		Terrains not favorable for the amplification of the phenomenon	Very low		
Local hazard Ril_e	Conditions of the architectural urban context $^{Rile}(3)$	High building density, very small distances between buildings. Very hard accessibility	Very high	–	$^{W}Ril_e$
		High building density, very small distances between buildings. Hard accessibility (eg medieval city)	High		
		Medium building density, reduced distances between buildings. Medium accessibility. (eg Renaissance or Modern city)	Medium		
		Low building density, large distances between buildings. Easy accessibility. (eg Contemporary city)	Low		
		Very low building density, large distances between buildings, isolated buildings. Easy accessibility.	Very low		
Vulnerability Vu (structure) $^{Vue}_str$	Links between structural elements $^{Vu}e_str(1)$	Not suitable links between the horizontal and vertical elements	Very high	$^{W}Vu\text{-}e_str(1)$	$^{W}Vu\text{-}e_str$
		Poorly adapted links between the horizontal and vertical elements	High		
		Partially adequate links between the horizontal and vertical elements	Medium		
		Adequate links between the horizontal and vertical elements	Low		
		Links between the horizontal and vertical elements very adequate	Very low		
	Horizontal structures (slab) $^{Vu}e_str(2)$	Not adopted interventions to adjust horizontal structures	Very high	$^{W}Vu\text{-}e_str(2)$	
		Not sufficiently adopted interventions to adjust horizontal structures	High		
		Partially adopted interventions to adjust horizontal structures	Medium		
		Sufficiently adopted interventions to adjust horizontal structures	Low		
		Adopted or unnecessary Interventions to adjust horizontal structures	Very low		
	Structural typology $^{Vu}e_str(3)$	Very low seismic resistance structure materials	Very high	$^{W}Vu\text{-}e_str(3)$	
		Low seismic resistance structure materials	High		
		Medium seismic resistance structure materials	Medium		
		High seismic resistance structure materials	Low		
		Very high seismic resistance structure materials	Very low		
	Wall quality $^{Vu}e_str(4)$	Not adopted measures of walls quality adjustments	Very high	$^{W}Vu\text{-}e_str(4)$	
		Insufficient measures of walls quality adjustments	High		
		Partially adopted measures of walls quality adjustments	Medium		
		Sufficient measures of walls quality adjustments	Low		
		Adopted or unnecessary measures of walls quality adjustments	Very low		
	Roof $^{Vu}e_str(5)$	Not adopted roof adjustment measures	Very high	$^{W}Vu\text{-}e_str(5)$	
		Insufficient roof adjustment measures	High		
		Partially adopted roof adjustment measures	Medium		
		Sufficient roof adjustment measures	Low		
		Adopted or unnecessary roof adjustment measures	Very low		
	Arch and vault $^{Vu}e_str(6)$	Not adopted arch and vault adjustment measures	Very high	$^{W}Vu\text{-}e_str(6)$	
		Adapting arch and vault made inadequately	High		
		Partially adopted arch and vault adjustment measures	Medium		
		Adapting arch and vault made sufficiently	Low		
		Adopted or unnecessary arch and vault adjustment measures	Very low		

(*continued on next page*)

Table B.3 (*continued*)

Parameter	Component	Description	Value	Component Weight	Parameter Weight
	Foundations ^{Vu}e_str(7)	Not adopted foundations adjustment measures	Very high	^{W}Vu-e_str(7)	
		Inadequate foundations adjustment measures	High		
		Partially adopted foundations adjustment measures	Medium		
		Sufficient foundations adjustment measures	Low		
		Adopted or unnecessary foundations adjustment measures	Very low		
	Resistant vertical elements ^{Vu}e_str(8)	Not adopted elements adjustment measures	Very high	^{W}Vu-e_str(8)	
		Insufficient measures of adjustment the elements	High		
		Partially adopted elements adjustment measures	Medium		
		Sufficient measures of adjustment the elements	Low		
		Adopted or unnecessary elements adjustment measures	Very low		
	Stairs ^{Vu}e_str(9)	Not adopted stairs adjustment measures	Very high	^{W}Vu-e_str(9)	
		Insufficient measures of adjustment the stairs	High		
		Partially adopted stairs adjustment measures	Medium		
		Sufficient measures of adjustment the stairs	Low		
		Adopted or unnecessary stairs adjustment measures	Very low		
	Building context ^{Vu}e_str(10)	Building not adjacent to other buildings or isolated	Very high	^{W}Vu-e_str(10)	
		Building partially adjacent to other buildings	High		
		Building adjacent to other buildings	Medium		
		Building partially connected to adjacent buildings	Low		
		Building connected effectively to adjacent buildings	Very low		
	Deterioration ^{Vu}e_str(11)	Presence of very important degradation elements	Very high	^{W}Vu-e_str(11)	
		Presence of important degradation elements	High		
		Presence of degradation elements of medium importance	Medium		
		Presence of degradation elements of low importance	Low		
		Not degradation elements	Very low		
	Deterioration by recent earthquake ^{Vu}e_str(12)	Presence of very important degradation elements	Very high	^{W}Vu-e_str(12)	
		Presence of important degradation elements	High		
		Presence of degradation elements of medium importance	Medium		
		Presence of degradation elements of low importance	Low		
		Not degradation elements	Very low		
Vulnerability Vu (form) ^{Vu}e_for	Non-structural elements ^{Vu}e_for(1)	Not adopted elements adjustment measures	Very high	^{W}Vu-e_for(1)	^{W}Vu-e_for
		Insufficient measures of adjustment the elements	High		
		Partially adopted elements adjustment measures	Medium		
		Sufficient measures of adjustment the elements	Low		
		Adopted or unnecessary elements adjustment measures	Very low		
	Planimetry configuration ^{Vu}e_for(2)	Not favorable configuration to counter the seismic event	Very high	^{W}Vu-e_for(2)	
		Little favorable configuration to counter the seismic event	High		
		Partially favorable configuration to counter the seismic event	Medium		
		Favorable configuration to counter the seismic event	Low		
		Very favorable configuration to counter the seismic event	Very low		
	Height configuration ^{Vu}e_for(3)	Not favorable configuration to counter the seismic event	Very high	^{W}Vu-e_for(3)	
		Little favorable configuration to counter the seismic event	High		
		Partially favorable to counter the seismic event	Medium		
		Favorable configuration to counter the seismic even	Low		
		Very favorable configuration to counter the seismic event	Very low		
	Aggregated volumes ^{Vu}e_for(4)	Very unfavorable presence of aggregated volumes	Very high	^{W}Vu-e_for(4)	
		Unfavorable presence of aggregated volumes	High		
		Partially unfavorable presence of aggregated volumes	Medium		
		Favorable presence of aggregated volumes	Low		
		Not aggregated volumes	Very low		
	Distribution type ^{Vu}e_for(5)	Very problematic distributive routes that make evacuation	Very high	^{W}Vu-e_for(5)	
		Problematic distributive routes that make evacuation	High		
		Distributive routes that partially facilitate evacuation	Medium		
		Distributive routes that facilitate evacuation	Low		
		Distributed routes for effective evacuation	Very low		
Vulnerability Vu (function) ^{Vu}f_fun	Functional typology Vu f_fun(1)	Public building with very high affluence	Very high	–	^{W}Vu-e_fun
		Public building with high affluence	High		
		Public building with medium affluence	Medium		
		Public building with low affluence	Low		
		Private or uninhabited building	Very low		

Appendix C. Set of weights obtained through the elaboration of the SMARTER questionnaire for fire, flood, and earthquake risks



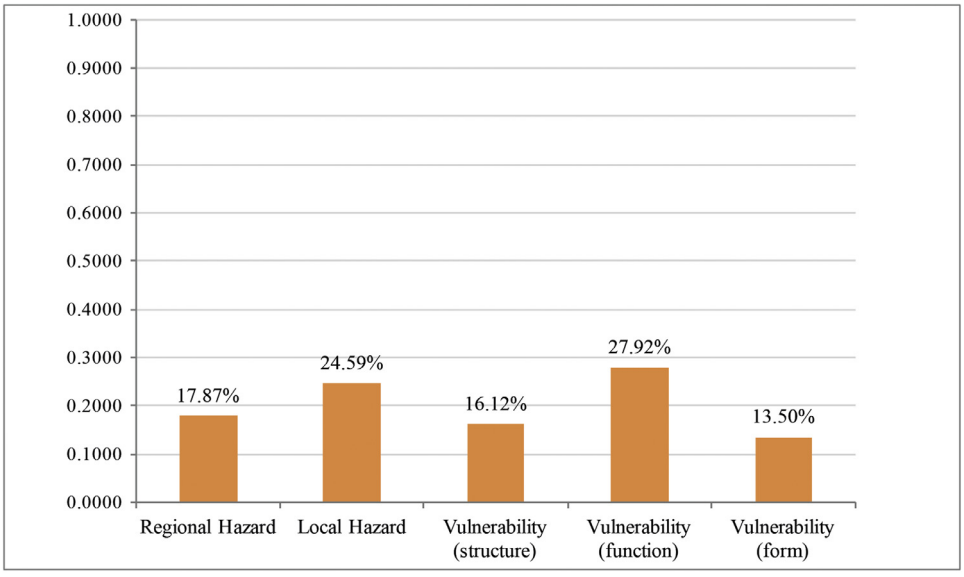


Fig. C.1. Weights of fire risk components and weights of fire risk parameters.

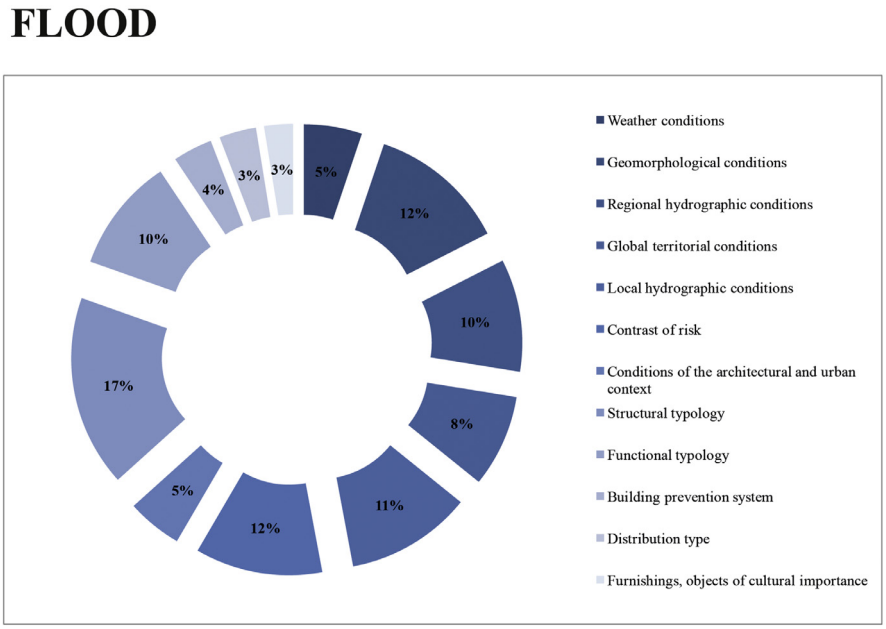
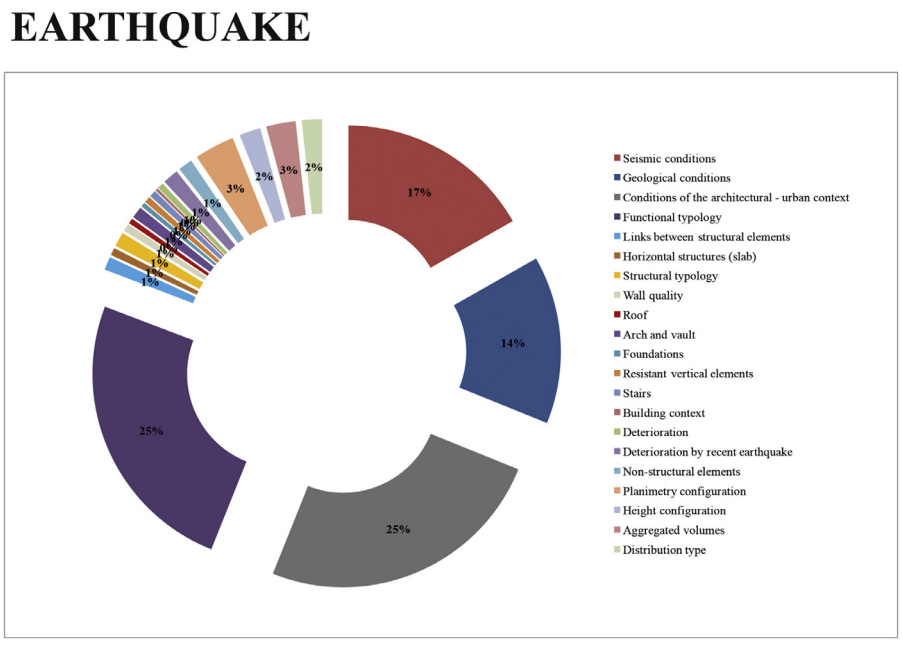
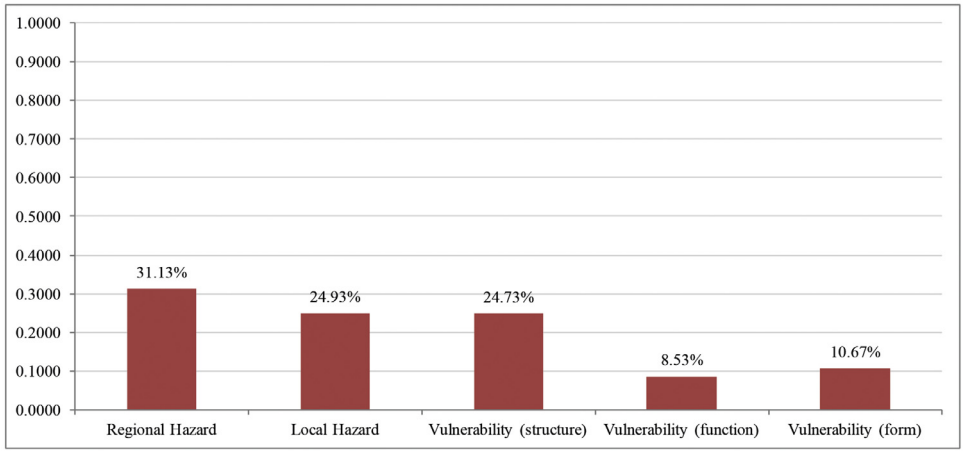


Fig. C.2. Weights of flood risk components and weights of flood risk parameters.



Weights of Earthquake Indicators



Weights of Earthquake General Aspects

Fig. C.3. Weights of earthquake risk components and weights of earthquake risk parameters.

Appendix D. ODE evaluation for the Santa Maria dei Miracoli Church

Table D.1
Evaluation of Church of Santa Maria dei Miracoli – Fire risk.

Church of Santa Maria dei Miracoli									
Fire									
Parameter (general)	*Component (local)*	*Local weight*	*General weight*	*Global weight*	*Local value*	*Num. Value*	*Norm Value*	*Local W. Value*[3]	*Global value*[4]
Probability (Rp)			–	–		100	1	–	–
	–	–							
Regional hazard (Rig_f)	Climatic conditions	0.2685	0.1835	0.0493	medium	3	0.6	0.1611	0.0296
	Weather conditions	0.1945	0.1835	0.0357	medium	3	0.6	0.1167	0.0214
	Territorial conditions	0.537	0.1835	0.0985	high	4	0.8	0.4296	0.0788
Local hazard (Ril_f)	Conditions of the architectural - urban context	0.3333	0.2493	0.0831	high	4	0.8	0.26664	0.0665
	Urban fire prevention system	0.6667	0.2493	0.1662	low	2	0.4	0.26668	0.0665
Formal Vulnerability (Vu_{f_form})	Distribution type	0.0993	0.1659	0.0165	low	2	0.4	0.03972	0.0066
	Furnishing, coatings, objects, non-structural elements	0.1474	0.1659	0.0245	high	4	0.8	0.11792	0.0196
	Objects of cultural importance contained in the building	0.1631	0.1659	0.0271	low	2	0.4	0.06524	0.0108
	Building fire prevention system	0.3335	0.1659	0.0553	very high	5	1	0.3335	0.0553
	Fire-fighting elements	0.3889	0.1659	0.0645	very low	1	0.1	0.07778	0.0129
Functional Vulnerability (Vu_{f_fun})	Functional typology	0.3889	0.2789	0.1085	medium	3	0.6	0.23334	0.0651
	Staff for emergency intervention	0.6111	0.2789	0.1704	high	4	0.8	0.48888	0.1363
Structural Vulnerability (Vu_{f_stru})	Type structure of the building	1	0.1224	0.1224	high	4	0.8	0.9	0.0979
								Total	**0.6673**

[3] Local weighted value = Local weight * Norm. value.
[4] Global value = Global weight * Norm. value.

Table D.2
Evaluation of Church of Santa Maria dei Miracoli – Flood risk.

Church of Santa Maria dei Miracoli									
Flood									
Parameter (general)	*Component (local)*	*Local weight*	*General weight*	*Global weight*	*Local value*	*Num. Value*	*Num. Value*	*Local W. Value*[5]	*Global value*[6]
Probability (Rp)		–	–	–		100	1	–	–
	–								
Regional hazard (Rig_f)	Weather conditions	0.1435	0.3674	0.0527	medium	3	0.6	0.0861	0.0316
	Geomorphological conditions	0.3264	0.3674	0.1199	high	4	0.8	0.26112	0.0959
	Regional hydrographic conditions	0.3056	0.3674	0.1123	low	2	0.4	0.12224	0.0449
	Global territorial conditions	0.2245	0.3674	0.0825	very low	1	0.2	0.0449	0.0165
Local hazard (Ril_f)	Local hydrographic conditions	0.3982	0.2782	0.1108	very low	1	0.2	0.07964	0.0222
	Contrast of risk	0.4167	0.2782	0.1159	very high	5	1	0.4167	0.1159
	Conditions of the architectural - urban context	0.1852	0.2782	0.0515	high	4	0.8	0.14816	0.0412
Formal Vulnerability (Vu_{f_form})	Building protection system	0.3856	0.0831	0.0320	very high	5	1	0.3856	0.0320
	Distribution type	0.3464	0.0831	0.0288	low	2	0.4	0.13856	0.0115
	Furnishing, objects, etc.	0.268	0.0831	0.0223	high	4	0.8	0.2144	0.0178
Functional Vulnerability (Vu_{f_fun})	Functional typology	1	0.1086	0.1086	medium	3	0.6	0.6	0.0652
Structural Vulnerability (Vu_{f_stru})	Structural typology	1	0.1626	0.1626	low	2	0.4	0.4	0.0065
								Total	**0.5599**

[5] Local weighted value = Local weight * Norm. value.
[6] Global value = Global weight * Norm. value.

Table D.3
Evaluation of Church of Santa Maria dei Miracoli – Earthquake risk.

Church of Santa Maria dei Miracoli									
Earthquake									
Parameter (general)	*Component (local)*	*Local weight*	*General weight*	*Global weight*	*Local value*	*Num. Value*	*Num. Value*	*Local W. Value*[7]	*Global value*[8]
Probability (Rp)	_	–	–	–		100	1	–	–
Regional hazard (Rig_e)	Seismic conditions	0.5278	0.3167	0.1672	low	2	0.4	0.21112	0.0669
	Geological conditions	0.4722	0.3167	0.1495	high	4	0.8	0.37776	0.1196
Local hazard (Ril_e)	Conditions of the architectural - urban context	1	0.2222	0.2222	high	4	0.8	0.8	0.1778
Functional Vulnerability (Vu_{e_fun})	Links between structural elements	0.1275	0.0978	0.0125	medium	3	0.6	0.03972	0.0066
	Horizontal structures (slab)	0.067	0.0978	0.0066	low	2	0.4	0.0765	0.0075
	Structural typology	0.1557	0.0978	0.0152	high	4	0.8	0.0268	0.0026
	Wall quality	0.0782	0.0978	0.0076	high	4	0.8	0.12456	0.0122
	Roof	0.0463	0.0978	0.0045	medium	3	0.6	0.06256	0.0061
	Arch and vault	0.1178	0.0978	0.0115	medium	3	0.6	0.02778	0.0027
	Foundations	0.0438	0.0978	0.0438	high	4	0.8	0.07068	0.0069
	Resistant verticals elements	0.0699	0.0978	0.0699	high	4	0.8	0.03504	0.0034
	Stairs	0.0717	0.0978	0.0717	very low	1	0.8	0.05592	0.0034
	Building context	0.0252	0.0978	0.0252	very high	5	0.2	0.01434	0.0055
	Deterioration	0.0626	0.0978	0.0626	low	2	1	0.0252	0.0014
	Deterioration by recent earthquake	0.1342	0.0978	0.1342	low	2	0.4	0.02504	0.0025
Formal Vulnerability (Vu_{e_form})	Non structural elements	0.1011	0.1089	0.0110	high	4	0.8	0.08088	0.0088
	Planimetry configuration	0.315	0.1089	0.0343	low	2	0.4	0.126	0.0137
	Height configuration	0.1664	0.1089	0.0181	low	2	0.4	0.06656	0.0072
	Aggregated volumes	0.2219	0.1089	0.0242	low	2	0.4	0.08876	0.0097
	Distribution type	0.2219	0.1089	0.0242	medium	3	0.6	0.13314	0.0145
Structural Vulnerability (Vu_{e_stru})	Functional typology	1	0.2544	0.2544	medium	3	0.6	0.6	0.1526
								Total	**0.6293**

[7] Local weighted value = Local weight * Norm. value.
[8] Global value = Global weight * Norm. value.

Appendix E. ODE evaluation for the Convent of San Nicola

Table E.1
Evaluation of Convent of San Nicola in Tolentino – Fire risk.

Convent of San Nicola in Tolentino									
Fire									
Parameter (general)	*Component (local)*	*Local weight*	*General weight*	*Global weight*	*Local value*	*Num. Value*	*Num. Value*	*Local W. Value*[9]	*Global value*[10]
Probability (Rp)	–	–	–	–		100	1	–	–
Regional hazard (Rig_f)	Climatic conditions	0.2685	0.1835	0.0493	medium	3	0.6	0.1611	0.0296
	Weather conditions	0.1945	0.1835	0.0357	medium	3	0.6	0.1167	0.0214
	Territorial conditions	0.537	0.1835	0.0985	high	4	0.8	0.4296	0.0788
Local hazard (Ril_f)	Conditions of the architectural - urban context	0.3333	0.2493	0.0831	very high	5	1	0.3333	0.0831
	Urban fire prevention system	0.6667	0.2493	0.1662	very high	5	1	0.6667	0.1662
Formal Vulnerability (Vu_{f_form})	Distribution type	0.0993	0.1659	0.0165	medium	3	0.6	0.05958	0.0099
	Furnishing, coatings, objects, non-structural elements	0.1474	0.1659	0.0245	very high	5	1	0.1474	0.0245
	Objects of cultural importance contained in the building	0.1631	0.1659	0.0271	very high	5	1	0.1631	0.0271
	Building fire prevention system	0.3335	0.1659	0.0553	very high	5	1	0.3335	0.0553
	Fire-fighting elements	0.3889	0.1659	0.0645	very high	5	1	0.3889	0.0645
Vulnerability Vu (function)	Functional typology	0.3889	0.2789	0.1085	high	4	0.8	0.31112	0.0868
	Staff for emergency intervention	0.6111	0.2789	0.1704	very high	5	1	0.6111	0.1704
Vulnerability Vu (structure)	Type structure of the building	1	0.1224	0.1224	medium	3	0.6	0.6	0.0734
								Total	**0.8910**

[9] Local weighted value = Local weight * Norm. value.
[10] Global value = Global weight * Norm. value.

Table E.2
Evaluation of Convent of San Nicola in Tolentino – Flood risk.

Convent of San Nicola in Tolentino									
Flood									
Parameter (general)	*Component (local)*	*Local weight*	*General weight*	*Global weight*	*Local value*	*Num. Value*	*Num. Value*	*Local W. Value*[11]	*Global value*[12]
Probability (Rp)	–	–	–	–	–	100	1	–	–
Regional hazard (Rig)	Weather conditions	0.1435	0.3674	0.0527	medium	3	0.6	0.0861	0.0316
	Geomorphological conditions	0.3264	0.3674	0.1199	high	4	0.8	0.26112	0.0959
	Regional hydrographic conditions	0.3056	0.3674	0.1123	medium	3	0.6	0.18336	0.0674
	Global territorial conditions	0.2245	0.3674	0.0825	medium	3	0.6	0.1347	0.0495
Local hazard (Ril)	Local hydrographic conditions	0.3982	0.2782	0.1108	low	2	0.4	0.15928	0.0443
	Contrast of risk	0.4167	0.2782	0.1159	very high	5	1	0.4167	0.1159
	Conditions of the architectural - urban context	0.1852	0.2782	0.0515	very high	5	1	0.1852	0.0515
Vulnerability Vu (form)	Building protection system	0.3856	0.0831	0.0320	very high	5	1	0.3856	0.0320
	Distribution type	0.3464	0.0831	0.0288	medium	3	0.6	0.20784	0.0173
	Furnishing, objects, etc.	0.268	0.0831	0.0223	high	4	0.8	0.2144	0.0178
Vulnerability Vu (function)	Functional typology	1	0.1086	0.1086	very high	5	1	1	01086
Vulnerability Vu (structure)	Structural typology	1	0.1626	0.1626	medium	3	0.6	0.6	0.0976
								Total	**0.7295**

[11] Local weighted value = Local weight * Norm. value.
[12] Global value = Global weight * Norm. value.

Table E.3
Evaluation of convent of San Nicola in Tolentino – Earthquake risk.

Convent of San Nicola in Tolentino									
Earthquake									
Parameter (general)	*Component (local)*	*Local weight*	*General weight*	*Global weight*	*Local value*	*Num. Value*	*Num. Value*	*Local W. Value*[13]	*Global value*[14]
Probability (Rp)	–	–	–	–		100	1	–	–
Regional hazard (Rig)	Seismic conditions	0.5278	0.3167	0.1672	high	4	0.8	0.42224	0.1337
	Geological conditions	0.4722	0.3167	0.1495	very high	5	1	0.4722	0.1495
Local hazard (Ril)	Conditions of the architectural - urban context	1	0.2222	0.2222	very high	5	1	1	0.2222
Vulnerability Vu (function)	Links between structural elements	0.1275	0.0978	0.0125	high	4	0.8	0.102	0.0100
	Horizontal structures (slab)	0.067	0.0978	0.0066	very high	5	1	0.067	0.0066
	Structural tipology	0.1557	0.0978	0.0152	high	4	0.8	0.12456	0.0122
	Wall quality	0.0782	0.0978	0.0076	medium	3	0.6	0.04692	0.0046
	Roof	0.0463	0.0978	0.0045	medium	3	0.6	0.02778	0.0027
	Arch and vault	0.1178	0.0978	00115	medium	3	0.6	0.07068	0.0069
	Foundations	0.0438	0.0978	0.0043	very high	5	1	0.0438	0.0043
	Resistant verticals elements	0.0699	0.0978	0.0068	medium	3	0.6	0.04194	0.0041
	Stairs	0.0717	0.0978	0.0070	medium	3	0.6	0.04302	0.0042
	Building context	0.0252	0.0978	0.0025	high	4	0.8	0.02016	0.0020
	Deterioration	0.0626	0.0978	0.0061	low	2	0.4	0.02504	0.0024
	Deterioration by recent earthquake	0.1342	0.0978	0.0131	very high	5	1	0.1342	0.0131
Vulnerability Vu (form)	Non structural elements	0.1011	0.1089	0.0110	very high	5	1	0.1011	0.0110
	Planimetry configuration	0.315	0.1089	0.0343	low	2	0.4	0.126	0.0137
	Height configuration	0.1664	0.1089	0.0181	medium	3	0.6	0.09984	0.0109
	Aggregated volumes	0.2219	0.1089	0.0242	very low	1	0.2	0.04438	0.0048
	Distribution type	0.2219	0.1089	0.0242	medium	3	0.6	0.13314	0.0145
Vulnerability Vu (structure)	Functional typology	1	0.2544	0.2544	very high	5	1	1	0.2544
								Total	**0.8879**

[13] Local weighted value = Local weight * Norm. value.
[14] Global value = Global weight * Norm. value.

References

[1] D. Alexander, The study of natural disasters, 1977–97: some reflections on a changing field of knowledge, Disasters 21 (2002) 284–304, doi:10.1111/1467-7717.00064.
[2] S. Kumpulainen, Vulnerability concepts in hazard and risk assessment, Spec. Pap. Geol. Surv. Finl. (2006).
[3] R. Jigyasu, V. Arora, Disaster risk management of cultural heritage in urban areas - a training guide, (2014) 90.
[4] M. Andretta, F. Coppola, A. Modelli, N. Santopuoli, L. Seccia, Proposal for a new environmental risk assessment methodology in cultural heritage protection, J. Cult. Herit. 23 (2017) 22–32, doi:10.1016/j.culher.2016.08.001.
[5] UNESCO (United Nations Educational, Scientific and Cultural Organisation)Convention Concerning the Protection of the World Cultural and Natural Heritage, 1972.
[6] UNESCO, Intergovernmental conference on cultural policies for development, Final Rep. (1998).
[7] V. Ferretti, M. Bottero, G. Mondini, Decision making and cultural heritage: an application of the Multi-Attribute Value Theory for the reuse of historical buildings, J. Cult. Herit. (2014), doi:10.1016/j.culher.2013.12.007.
[8] UNDRR (United Nations International Strategy for Disaster Risk Reduction)Hyogo framework for action 2005-2015: building the resilience of Nations and Communities to Disasters, 2005.
[9] UNISDR (United Nations Office for Disaster Risk Reduction), Sendai framework for disaster risk reductionUN World Conf, 2015.
[10] Icomos, International Charter for the conservation and restoration of monuments and sites (The Venice Charter 1964)IInd Int. Congr. Archit. Tech. Hist. Monum., 1964.
[11] M. Heylin, Disaster, Chem. Eng. News 64 (1986) 3, doi:10.1021/cen-v064n005.p003.
[12] X. Romão, C. Bertolin, Risk protection for cultural heritage and historic centres: current knowledge and further research needs, Int. J. Disaster Risk Reduct. 67 (2022) 102652, doi:10.1016/j.ijdrr.2021.102652.
[13] UNISDR (United Nations Office for Disaster Risk Reduction), Sendai framework data readiness review 2017, Disaster-related Data for Sustainable Development, 2017.
[14] E. Colucci, F. Matrone, F. Noardo, V. Assumma, G. Datola, F. Appiotti, M. Bottero, F. Chiabrando, P. Lombardi, M. Migliorini, E. Rinaldi, A. Spanò, A. Lingua, Documenting cultural heritage in an INSPIRE-based 3D GIS for risk and vulnerability analysis, J. Cult. Herit. Manag. Sustain. Dev. (2022), doi:10.1108/JCHMSD-04-2021-0068.
[15] J. Taboroff, Cultural heritage and natural disasters : for risk management incentives and mitigation, Disaster Risk Manag. Ser. No. 2 Manag. Disaster Risk Emerg. Econ., 2000.
[16] A. de la Poterie, M.A. Baudoin, From Yokohama to Sendai: approaches to participation in international disaster risk reduction frameworks, Int. J. Disaster Risk Sci. 6 (2015), doi:10.1007/s13753-015-0053-6.
[17] UNDRR (United Nations Office for Disaster Risk Reduction), Yokohama Strategy and plan of action for a safer world: guidelines for natural disaster prevention, preparedness and mitigation, in: World Conference on Natural Disaster Reduction, Yokohama, Japan, 1994, pp. 23–27.
[18] J. Vermaak, D. van Niekerk, Disaster risk reduction initiatives in South Africa, Dev. South. Afr. (2004), doi:10.1080/0376835042000265487.
[19] Rescult, in: The RESCULT team: what has been done, 2017, pp. 4–6.
[20] Rescult, in: NEWSLETTER 4 /2018 this is the 2nd RESCULT newsletter ! What has been done EID conceptualization, 2018, pp. 1–5.
[21] F. Chiabrando, V. Donato, M. Lo Turco, C. Santagati, Cultural heritage documentation, analysis and management using building information modelling: state of the art and perspectives, in: 2018. https://doi.org/10.1007/978-3-319-68646-2_8.
[22] F. Appiotti, V. Assumma, M. Bottero, P. Campostrini, G. Datola, P. Lombardi, E. Rinaldi, Definition of a risk assessment model within a European interoperable database platform (EID) for cultural heritage, J. Cult. Herit. 46 (2020) 268–277, doi:10.1016/j.culher.2020.08.001.
[23] F. Appiotti, V. Assumma, M. Bottero, P. Campostrini, G. Datola, E. Rinaldi, Un modello di valutazione del rischio per il Patrimonio Culturale, RIV Rass. Ital. di Valutazione (2018) 121–148, doi:10.3280/RIV2018-071007.
[24] A. Krstić, J. Figueira, S. Greco, M. Ehrgott, Multicriteria decision analysis: state of the art surveys, Springer-Verlag, New York, NY, 2016, Ekon. Horizonti. 20 (2018) 189–191, doi:10.5937/ekonhor1802189K.
[25] W. Edwards, D. von Winterfeldt, D.L. Moody, in: Simplicity in Decision Analysis: An Example and a Discussion, in: Decis. Mak, Cambridge University Press, New York, NY, US, 1988, pp. 443–464, doi:10.1017/CBO9780511598951.022.

[26] F.H. Barron, B.E. Barrett, The efficacy of SMARTER — simple multi-attribute rating technique extended to ranking, Acta Psychol. 93 (1996) 23–36, doi:10.1016/0001-6918(96)00010-8.
[27] M. Piana, W. Wolters, Santa Maria dei Miracoli a Venezia. La storia, la fabbrica, i restauri, Venezia, 2003.
[28] L. Totaro, Un approccio integrato per la valutazione dei beni culturali., (2018).
[29] EN 1998-1, Eurocode 8 - design of structures for earthquake resistance - Part 1, Buildings (2004) 229.
[30] F. Torrieri, A. Oppio, M. Rossitti, Damage assessment for architectural heritage: the Cavallerizza Reale complex in Turin /La stima dei danni al patrimonio architettonico: il caso della Cavallerizza Reale di Torino, Valori e Valutazioni. 30 (2022) 71–84. https://doi.org/10.48264/VVSIEV-20223005.
[31] V. Assumma, M. Bottero, G. Datola, E. De Angelis, R. Monaco, Dynamic models for exploring the resilience in territorial scenarios, Sustainability 12 (2019) 3, doi:10.3390/su12010003.
[32] M. Bottero, G. Datola, R. Monaco, Exploring the resilience of urban systems using fuzzy cognitive maps, in: Lect. Notes Comput. Sci. (Including Subser. Lect. Notes Artif. Intell. Lect. Notes Bioinformatics), 2017, pp. 338–353, doi:10.1007/978-3-319-62398-6_24.
[33] T.M. Ferreira, R.Ramírez Eudave, Assessing and managing risk in historic urban areas: current trends and future research directions, Front. Earth Sci. 10 (2022) 1–17, doi:10.3389/feart.2022.847959.
[34] L. Davis, T. Larionova, D. Patel, D. Tse, P. Baquedano Juliá, P. Pinto Santos, T.M. Ferreira, Flood vulnerability and risk assessment of historic urban areas: vulnerability evaluation, derivation of depth-damage curves and cost–benefit analysis of flood adaptation measures applied to the historic city centre of Tomar, Portugal, J. Flood Risk Manag. 16 (2023) e12908, doi:10.1111/jfr3.12908.
[35] N.C. Palazzi, P.B. Juliá, T.M. Ferreira, J. Rosas, M. Monsalve, J.C. de la Llera, Fire risk assessment of historic urban Aggregates:an application to the Yungay neighborhood in Santiago, Chile, Int. J. Disaster Risk Reduct. 86 (2023) 103550, doi:10.1016/j.ijdrr.2023.103550.
[36] G. Datola, V. Assumma, M. Bottero, Assessing the economic value of the unmovable cultural assets for improving their resilience: the case study of the Church of Santa Maria dei Miracoli, Lect. Notes Networks Syst. (2022) 2565–2574, doi:10.1007/978-3-031-06825-6_245.
[37] I. Maltese, I. Mariotti, A. Oppio, F. Boscacci, Assessing the benefits of slow mobility connecting a cultural heritage, J. Cult. Herit. 26 (2017) 153–159, doi:10.1016/j.culher.2017.01.006.
[38] A. Oppio, M. Bottero, V. Ferretti, Designing adaptive reuse strategies for cultural heritage with choice experiments, in: S. Stanghellini, P. Morano, M. Bottero, A. Oppio (Eds.), Apprais. From Theory to Pract. Results SIEV 2015, Springer International Publishing, Cham, 2017, pp. 303–315, doi:10.1007/978-3-319-49676-4_23.
[39] S. Corrente, J.R. Figueira, S. Greco, Pairwise comparison tables within the deck of cards method in multiple criteria decision aiding, Eur. J. Oper. Res. 291 (2021) 738–756, doi:10.1016/J.EJOR.2020.09.036.
[40] M. Bottero, C. D'Alpaos, A. Oppio, Ranking of adaptive reuse strategies for abandoned industrial heritage in vulnerable contexts: a multiple criteria decision aiding approach, Sustain (2019), doi:10.3390/su11030785.
[41] V. Assumma, M. Bottero, R. Monaco, G. Mondini, Assessing the landscape value: an integrated approach to measure the attractiveness and pressures of the vineyard landscape of piedmont (Italy), Smart Innov. Syst. Technol. (2019), doi:10.1007/978-3-319-92102-0_27.
[42] V. Assumma, M. Bottero, G. Datola, A. Pezzoli, Climate change and urban resilience. Preliminary insights from an integrated evaluation framework, in: 2021: pp. 1–10.
[43] M. Bottero, E. Comino, F. Dell'Anna, L. Dominici, M. Rosso, Strategic assessment and economic evaluation: the case study of Yanzhou Island (China), Sustain (2019), doi:10.3390/su11041076.
[44] M. Bottero, C. Caprioli, G. Cotella, M. Santangelo, Sustainable cities: a reflection on potentialities and limits based on existing eco-districts in Europe, Sustainability 11 (2019) 5794, doi:10.3390/su11205794.
[45] M. Barbati, J.R. Figueira, S. Greco, A. Ishizaka, S. Panaro, A multiple criteria methodology for priority based portfolio selection, Socioecon. Plann. Sci. 88 (2023) 101595, doi:10.1016/j.seps.2023.101595.
[46] A. Salo, J. Keisler, A. Morton, Portfolio Decision Analysis: Improved Methods For Resource Allocation, Springer New York, 2011 https://books.google.it/books?id=ilqecQsA1bAC.
[47] C. De Caparica, C. Caparica, Conservation science cultural heritage risk analysis models : an overview, Int. J. Conserv. Sci. 10 (2019) 39–58 file:///D:/kantor/kti/2020/canal/metode/cultural heritage risk analysis models, an aver view.pdf.
[48] X. Romão, E. Paupério, N. Pereira, A framework for the simplified risk analysis of cultural heritage assets, J. Cult. Herit. 20 (2016) 696–708, doi:10.1016/j.culher.2016.05.007.
[49] E. Galán, P. Aparicio, The environmental risk assessment applied to cultural heritage. A methodological approach, Conserv. Manag. Conf. (2013) 1405–1409 https://www.researchgate.net/publication/260035494_The_environmental_risk_assessment_applied_to_cultural_heritage_A_methodological_approach.
[50] D. D'Ayala, A. Ansal, Local site conditions and seismic risk assessment of historic buildings, in: Geotech. Eng. Preserv. Monum. Hist. Sites, CRC Press, 2013, pp. 45–56, doi:10.1201/b14895-6.
[51] L.G.F. Salazar, X. Romão, E. Paupério, Review of vulnerability indicators for fire risk assessment in cultural heritage, Int. J. Disaster Risk Reduct. 60 (2021) 102286, doi:10.1016/j.ijdrr.2021.102286.
[52] G. Sevieri, C. Galasso, D. D'Ayala, R. De Jesus, A. Oreta, M.E.D.A. Grio, R. Ibabao, A multi-hazard risk prioritisation framework for cultural heritage assets, Nat. Hazards Earth Syst. Sci. 20 (2020) 1391–1414, doi:10.5194/nhess-20-1391-2020.
[53] G. Forino, J. MacKee, J. von Meding, A proposed assessment index for climate change-related risk for cultural heritage protection in Newcastle (Australia), Int. J. Disaster Risk Reduct. 19 (2016) 235–248, doi:10.1016/j.ijdrr.2016.09.003.
[54] G. O'Brien, P. O'Keefe, J. Jayawickrama, R. Jigyasu, Developing a model for building resilience to climate risks for cultural heritage, J. Cult. Herit. Manag. Sustain. Dev. 5 (2015) 99–114, doi:10.1108/JCHMSD-06-2013-0021.
[55] G. Li, H. Yuan, Y. Shan, G. Lin, G. Xie, A. Giordano, Architectural cultural heritage conservation: fire risk assessment of ancient vernacular residences based on FAHP and EWM, Appl. Sci. (2023) 13, doi:10.3390/app132212368.
[56] C. Arrighi, F. Castelli, B. Mazzanti, Floods and cultural heritage: risk assessment and management for the city of Florence, Italy, in: Sustain. Hydraul. Era Glob. Chang., CRC Press, 2016, pp. 871–876, doi:10.1201/b21902-145.
[57] A. Momčilović Petronijević, P. Petronijević, Floods and their impact on cultural heritage—a case study of southern and Eastern Serbia, Sustainability 14 (2022) 14680, doi:10.3390/su142214680.
[58] F. Zaina, A risk assessment for cultural heritage in Southern Iraq: framing drivers, threats and actions affecting archaeological sites, Conserv. Manag. Archaeol. Sites. 21 (2019) 184–206, doi:10.1080/13505033.2019.1662653.
[59] R. Figueiredo, X. Romão, E. Paupério, Flood risk assessment of cultural heritage at large spatial scales: framework and application to mainland Portugal, J. Cult. Herit. 43 (2020) 163–174, doi:10.1016/j.culher.2019.11.007.