12th INTERNATIONAL CONFERENCE ON STRUCTURAL ANALYSIS OF HISTORICAL CONSTRUCTIONS

SAHC 2021

Online event, 29 Sep - 1 Oct, 2021

P. Roca, L. Pelà and C. Molins (Eds.)

A publication of:

International Centre for Numerical Methods in Engineering (CIMNE)
Barcelona, Spain

CIMNE

ISBN: 978-84-123222-0-0

Printed by: Artes Gráficas Torres S.L., Huelva 9, 08940 Cornellà de Llobregat, Spain

12th INTERNATIONAL CONFERENCE ON STRUCTURAL ANALYSIS OF HISTORICAL CONSTRUCTIONS

SAHC 2021

Online event, 29 Sep - 1 Oct, 2021

TABLE OF CONTENTS

PREFACE

The International Conference on Structural Analysis of Historical Constructions (SAHC) was first celebrated in Barcelona in 1995, followed by a second edition also in Barcelona in 1998. Since then, nine subsequent editions have been organized in different countries of Europe, America and Asia. The SAHC conference series is intended to offer a forum allowing engineers, architects and all experts to share and disseminate state-of-art knowledge and novel contributions on principles, methods and technologies for the study and conservation of heritage structures. Through all its successful past editions, the SAHC conference has become one of the topmost periodical opportunities for scientific exchange, dissemination and networking in the field.

During the last decades the study and conservation of historical structures has attained high technological and scientific standards. Today's practice involves the combination of innovative non-destructive inspection technologies, sophisticated monitoring systems and advanced numerical models for structural analysis. More than ever, it is understood that the studies must be performed by interdisciplinary teams integrating wide expertise (engineering, architecture, history, archeology, geophysics, chemistry…). Moreover, the holistic nature of the studies, and the need to encompass and combine the different scales of the problem –the materials, the structures, the building aggregates, and the territory – are now increasingly acknowledged. Due to all this, the study of historical structures is still facing very strong challenges that can only be addressed through sound international scientific cooperation.

Taking these ideas in mind, the 12th edition of the SAHC conference aimed at creating a new opportunity for the exchange and discussion of novel concepts, technologies and practical experiences on the study, conservation and management of historical constructions.

The present proceedings include the papers presented to the conference, which was finally celebrated on September 29-30 and October 1, 2021, in an on-line mode due to the word sanitary emergency situation created by the Covid-19 pandemic.

The conference included the following topics: history of construction and building technology; inspection methods, non-destructive techniques and laboratory testing; numerical modeling and structural analysis; structural health monitoring; repair and strengthening strategies and techniques; conservation of 20th c. architectural heritage; seismic analysis and retrofit; vulnerability and risk analysis and interdisciplinary projects and case studies.

The SAHC 2021 conference has been possible thanks to the large contribution of the scientific committee and reviewer panel who took care of selecting and review the papers submitted. The contribution of the different sponsors and supporting organizations is also acknowledged. Above all, the conference has been possible thanks to all the authors who have contributed with very valuable papers despite the difficulties caused by the world pandemic. New editions of the conference are already planned in normal face-to-face formats which, in the upcoming years, will provide new opportunities for sharing valuable knowledge and experience on structural conservation, as well as for keeping alive and fulfilling the purpose and aims of the SAHC conference series.

The Organizing Committee

PREFACE

The International Conference on Structural Analysis of Historical Constructions (SAHC) was first celebrated in Barcelona in 1995, followed by a second edition also in Barcelona in 1998. Since then, nine subsequent editions have been organized in different countries of Europe, America and Asia. The SAHC conference series is intended to offer a forum allowing engineers, architects and all experts to share and disseminate state-of-art knowledge and novel contributions on principles, methods and technologies for the study and conservation of heritage structures. Through all its successful past editions, the SAHC conference has become one of the topmost periodical opportunities for scientific exchange, dissemination and networking in the field.

During the last decades the study and conservation of historical structures has attained high technological and scientific standards. Today's practice involves the combination of innovative non-destructive inspection technologies, sophisticated monitoring systems and advanced numerical models for structural analysis. More than ever, it is understood that the studies must be performed by interdisciplinary teams integrating wide expertise (engineering, architecture, history, archeology, geophysics, chemistry…). Moreover, the holistic nature of the studies, and the need to encompass and combine the different scales of the problem –the materials, the structures, the building aggregates, and the territory – are now increasingly acknowledged. Due to all this, the study of historical structures is still facing very strong challenges that can only be addressed through sound international scientific cooperation.

Taking these ideas in mind, the 12th edition of the SAHC conference aimed at creating a new opportunity for the exchange and discussion of novel concepts, technologies and practical experiences on the study, conservation and management of historical constructions.

The present proceedings include the papers presented to the conference, which was finally celebrated on September 29-30 and October 1, 2021, in an on-line mode due to the word sanitary emergency situation created by the Covid-19 pandemic.

The conference included the following topics: history of construction and building technology; inspection methods, non-destructive techniques and laboratory testing; numerical modeling and structural analysis; structural health monitoring; repair and strengthening strategies and techniques; conservation of 20th c. architectural heritage; seismic analysis and retrofit; vulnerability and risk analysis and interdisciplinary projects and case studies.

The SAHC 2021 conference has been possible thanks to the large contribution of the scientific committee and reviewer panel who took care of selecting and review the papers submitted. The contribution of the different sponsors and supporting organizations is also acknowledged. Above all, the conference has been possible thanks to all the authors who have contributed with very valuable papers despite the difficulties caused by the world pandemic. New editions of the conference are already planned in normal face-to-face formats which, in the upcoming years, will provide new opportunities for sharing valuable knowledge and experience on structural conservation, as well as for keeping alive and fulfilling the purpose and aims of the SAHC conference series.

The Organizing Committee

SUPPORTING ORGANIZATIONS

Universitat Politècnica de Catalunya (UPC), Barcelona, Spain

Center for Numerical Methods in Engineering (CIMNE), UPC, Spain

International Council on Monuments and Sites (ICOMOS)

International Scientific Committee for Analysis and Restoration of Structures of Architectural Heritage of ICOMOS (ICOMOS / ISCARSAH)

ORGANIZERS AND COMMITTEES

Organizing Committee

Pere Roca

Technical University of Catalonia

Climent Molins

Technical University of Catalonia

Luca Pelà

Technical University of Catalonia

Paulo Lourenço

University of Minho

Claudio Modena

University of Padova

SCIENTIFIC COMMITTEE

National Members

- Jose M. Adam, Polytechnic University of Valencia
- Ernest Bernat, Polytechnic University of Catalonia
- Pedro Calderón, Polytechnic University of Valencia
- Miguel Cervera, Polytechnic University of Catalonia
- Victor Compán, University of Seville
- Leire Garmendia, University of the Basque Country
- Lluis Gil, Polytechnic University of Catalonia
- Pilar Giráldez, University of Barcelona
- Salvador Ivorra, University of Alicante
- Miquel Llorens, University of Girona
- Ignacio Lombillo, University of Cantabria
- Camilla Mileto, Polytechnic University of Valencia
- Javier Mosteiro, Technical University of Madrid
- Belén Riveiro, University of Vigo
- Savvas Saloustros, Polytechnic University of Catalonia
- Fernando Vegas, Polytechnic University of Valencia
- Marius Vendrell, University of Barcelona

International Members

- Rafael Aguilar, Pontifical Catholic University of Peru
- Takayoshi Aoki, Nagoya City University
- Alessandra Aprile, University of Ferrara
- Oriol Arnau, National Autonomous University of Mexico
- Görün Arun, Yildiz Technical University
- Hiram Badillo, Autonomous University of Zacatecas
- Andrea Benedetti, University of Bologna
- Rita Bento, University of Lisbon
- Katrin Beyer, Swiss Federal Institute of Technology in Lausanne
- Rubén Boroschek, University of Chile
- Guido Camata, University of Chieti-Pescara
- Claudia Cancino, Getty Conservation Institute
- Eva Coïsson, University of Parma
- Dina D'Ayala, University College London
- Gianmarco de Felice, Roma Tre University
- Gianfranco de Matteis, University of Campania
- Matthew DeJong , University of California at Berkeley
- Milos Drdácký , Institute of Theoretical and Applied Mechanics
- Khalid El Harrouni, National School of Architecture
- Ahmed Elyamani, Cairo University
- Yohei Endo, Shinshu University
- Mariana Esponda, Carleton University
- Antonio Formisano, University of Naples Federico II
- Dora Foti, University of Bari
- Enrico Garbin, University of Padova
- Giorgia Giardina, University of Cambridge

- Toshikazu Hanazato, Mie University
- Mehrdad Hejazi, University of Isfahan
- Marcela Hurtado, Federico Santa María Technical University
- Jason Ingham, University of Auckland
- Wolfram Jager, Techincal University Dresden
- Stephen J. Kelley, SJK Inc.
- Debra Laefer, New York University
- Sergio Lagomarsino, University of Genova
- Alessandra Marini, University of Bergamo
- Guillermo Martínez, Michoacan University of Saint Nicholas of Hidalgo
- Arun Menon, Indian Institute of Technology Madras
- Gabriele Milani, Polytechnic University of Milan
- John Ochsendorf, Massachusetts Institute of Technology
- Daniel Oliveira, University of Minho
- Fernando Peña, National Autonomous University of Mexico
- Andrea Penna, University of Pavia
- Maurizio Piazza, University of Trento
- Mariapaola Riggio, Oregon State University
- Jan Rots, Delft University of Technology
- Antonella Saisi, Polytechnic University of Milan
- Cristián Sandoval, Pontifical Catholic University of Chile
- Vasilis Sarhosis, The University of Leeds
- Yaacov Schaffer, Israel Antiquities Authority
- Nigel Shrive, University of Calgary
- Marek Sklodowski, Institute of Fundamental Technological Research
- Pierre Smars, National Yunlin University of Science and Technology
- Luigi Sorrentino, Sapienza University of Rome
- Enrico Spacone, University of Chieti-Pescara
- Nicola Tarque, Pontifical Catholic University of Peru
- Adrienn Tomor, University of the West of England
- Daniel Torrealva, Pontifical Catholic University of Peru
- Maria Rosa Valluzzi, University of Padova
- Koenraad Van Balen, KU Leuven
- Humberto Varum, University of Porto
- Els Verstrynge, KU Leuven
- Elizabeth Vintzileou, National Technical University of Athens
- Roko Žarnić, University of Ljubljana

REVIEWER PANEL

- Daniela Addessi
- Maurizio Angelillo
- Jesus Bairán
- Elisa Bertolesi
- Maria Bostenaru
- Giuseppe Brando
- Manuel Buitrago Moreno
- Albert Cabané
- Chiara Calderini
- Ivo Caliò
- Lorenzo Cantini
- Silvia Caprili
- Giuliana Cardani
- Claudia Casapulla
- Rosario Ceravolo
- Francesca Ceroni
- Francesco Clementi
- Camilla Colla
- Cossima Cornadó
- Sara Dimovska
- Anastasios Drougkas
- Chiara Ferrero
- Virginia Flores Sasso
- Aguinaldo Fraddosio
- Donald Friedman
- Stefano Galassi
- Larisa García-Ramonda
- Lucia Garijo
- Carmelo Gentile
- Lorenzo Jurina
- Philip Karklbrenner
- David López
- Jose Machado
- Nirvan Makoond
- Nuno Mendes
- Andronki Miltiadou
- Bernt Mittnacht
- Tom Morrison
- Marius Mosoarca
- Juan Murcia
- Federica Ottoni
- Bartolomeo Pantò
- Marisa Pecce
- Chiara Pepi
- Elisa Poletti
- Bora Pulatsu
- Enrico Quagliarini
- Luisa Rovero
- Nicola Ruggieri
- Santiago Sanchez
- Mario Santana
- Michel Schuller
- Jorge Segura
- Vincenzo Sepe
- Alberto Taliercio
- Dimitris Theodossopoulos
- Filippo Ubertini
- Giuseppina Uva
- Graça Vasconcelos
- Maria Belén Jiménez

SPONSORS

PRO_SAM is a plugin which connects PRO_SAP with SAM II solver, a powerful tool for pushover analysis of new and existing structures.

SOLVER RELIABILITY

SAM II, conceived by Prof. Magenes, Eng. Manzini and Eng. Morandi, is a well-known and robust non-linear solver highly referenced in international literature.

CODES OF PRACTICE

Eurocode 8, Italian codes.

MATERIALS

Unreinforced and reinforced masonry, reinforced concrete and generic linear materials.

LOCAL FAILURE MECHANISMS

Automatic geometry interfacing with PRO_CineM for kinematic linear and non-linear analyses.

LINEAR ANALYSIS

Automatic generation of plate and shell linear model from the equivalent frame.

FREE

PRO_SAM is free for students, scholars or scientific research.

Asdea Software S.r.l. is part of the burgeoning ASDEA brand, which includes ASDEA S.r.l. and ASDEA Hardware. We are a software development company staffed with engineers, researchers, and software developers. Our goal is to provide innovative software solutions customized for clients and of original in-house design for numerical simulation and data visualization. We are the company behind the revolutionary software STKO (Scientific ToolKit for OpenSees). More than just a simple GUI, STKO features a Python scripting interface, meaning that users can customize and program the already powerful pre and postprocessors as needed, harnessing the full power of OpenSees.

CALSENS develops state-of-the-art fiber-optic sensors and designs, deploys and operates structural health monitoring (SHM) solutions to monitor bridges, buildings and vehicles (ships, airplanes, UAV), among other structures. Our services are based on constant research and innovation, creating products and services at the frontier of knowledge.

CALSENS services cover the full process of monitoring. Starting from the modelling of structural behavior and choice of control parameters, continuing with the election, design, fabrication and installation of the sensors and sensing system, until the processing, interpretation and evaluation of the data.

CALSENS has a multidisciplinary team with a high degree of expertise in the fields of civil engineering, photonic technologies, signal processing, materials engineering or computing.

12th International Conference on Structural Analysis of Historical Constructions
SAHC 2020
P. Roca, L. Pelà and C. Molins (Eds.)

RISK MANAGEMENT AND BUILT HERITAGE: TOWARDS A SYSTEMATIC APPROACH

ANTHOULA KONSTA[1*] AND STEFANO DELLA TORRE[1]

[1]Department of Architecture, Building environment and Construction engineering (ABC)
Politecnico di Milano
31 Ponzio St., 20133 Milan, Italy
e-mail: anthoula.konsta@polimi.it, stefano.dellatorre@polimi.it; www.abc.polimi.it
(*corresponding author)

Keywords: Risk Classification, Risk Assessment, Risk Management, Built Heritage Management

Abstract. *This paper discusses the classification of risks as a tool for the identification, the assessment and the management of risks for the built heritage. Existing typologies of risk vary according to the selected criteria on which they are based and their utility within the risk management process. Indicative examples of risk classifications proposed and used in the field of cultural heritage management, as well as in other fields, are examined. The comparison of the selected criteria for analysing risks and the reflection upon their relevant aspects to the built heritage conservation provide a frame for a systematic approach to the built heritage management.*

1 INTRODUCTION

During the last thirty years, the risk management methodology has been recognised as an effective approach to the conservation decision-making process. Among the various efforts that have been made to develop coherent and clear procedures for the risk management in the field of cultural heritage, the experience carried out in museums preventive conservation practices stands out.

With respect to the field of built heritage, we can notice the prevalence of a fragmentary vision of the problems and their solution. Indeed, many methods have been elaborated for the analysis of the different risks to which built heritage is exposed. From air pollution and acid rain to natural hazards, and from inappropriate intervention and use to mass tourism, we can find a relevant number of studies and practice involving respectively numerous specialists and skills from a variety of fields. Naturally, this kind of "separation" arises from the necessity to deepen the knowledge of the different problems and their solution and it cannot be undoubtedly considered as a stumbling block. The problem emerges from the difficulty to coordinate interdisciplinarity, to understand multifaceted problems, and to put together all the findings.

With the aim to frame a more methodical and holistic approach to the built heritage risk management, firstly, the different parts of a risk management process are examined, and their main characteristics, as well as their relationship are underlined. Secondly, different risk classification schemes are discussed with regard to their usefulness and practicality to respond to the diverse needs of the process.

2 RISK ASSESSMENT IN RELATION TO RISK MANAGEMENT

2.1 The importance of meaningful measurements for a successful risk management

David J. Ball [1] in his article about the evolution of risk-based thinking describes the contribution of the studies of mathematicians and scientists during the 17th and 18th centuries to the development of risk based approaches to the first insurance companies. The mathematical calculation of the probability of future adverse events in a defined period and the wide range of its application has given rise, in the 20th century, to the extension of risk management approaches from the financial and insurance sectors to the industrial and public health sectors

Similarly, Douglas W. Hubbard in his brief history of risk management highlights the determinant role of probability theory and statistics in assessing risks: "[…] throughout most of human history, we were dealing with only half of the risk management problem, at most. From Babylon through the Middle Ages, risk management was an unguided mitigation of risks. Choosing what risks to prepare for was always a matter of gut feel. What differentiates risk management since the start of the Age of Enlightenment is in part a more systematic approach to assessing the risk. The development of probability theory and statistics in the 17th century allowed for risk to be quantified in a meaningful way" [2, p. 22].

However, Hubbard warns that the predominant approach to risk management is not based on actual measurements of risks. Indeed, the probabilistic models will be adopted only in select industries for select applications, such as the quantitative methods used in insurance and financial industry, as well as the "probabilistic risk analysis" used in engineering. In contrast, many of the risk analysis techniques adopted and widely used by consultants and standards are based on arbitrary and ineffectual scoring approaches that are not supported by any theoretical or empirical analysis. In addition, he concludes, "if the initial assessment of risk is not based on meaningful measures, the risk mitigation methods, even if they could have worked, are bound to address the wrong problems. If risk assessment is a failure, then the best case is that risk management effort is simply a waste of time and money because decisions are ultimately unimproved. In the worst case, the erroneous conclusions lead the organization down a more dangerous path that it would be probably not have otherwise taken" [2, p. 6].

2.2 Risk analysis for better decisions

The big influence of risk-based approaches over all the agencies has been determined not because of the willingness to reduce all risks (Ball considers three factors, firstly the lack of resources, secondly the non-exclusive interest for risks, and thirdly the positive aspects of risky activities), but as a consequence of the capacity to prioritise the activities when managing a great number of risks, and above all to reach efficient decisions [1].

In this perspective, the definition of acceptable-risk problems and the critical analysis of the viability of various approaches to decision making offered by Fischhoff et al [3] is very relevant. As stated in their report, "risk acceptable problems are decision problems, i.e. they require a choice between alternatives. That choice depends upon the alternatives, values, and beliefs that are considered" [3, pp. ii, 4-6]. As for the decision making methods, three categories have been identified and analysed: professional judgment, bootstrapping techniques and formal analysis, such as the cost/benefit analysis or the multi-criteria analysis.

Similarly, Kaplan and Garrick [4] in the light of two quantitative definitions of risk they discussed the notion of risk acceptability and argued that “[…] the purpose of risk analysis and risk quantification is always to provide input to an underlying decision problem which involves not just risks but also other forms of costs and benefits. Risk must thus be considered always within a decision theory context. Within this context, that risk is acceptable, which comes along with the optimum decision option, all other risks are unacceptable, even if smaller”.

Thus, risk assessment is only one phase in the process of risk management. It is the technical estimation of risks or else the “tool of gaining knowledge about the risks” and consists in identifying hazards, assessing their probabilities and measuring their consequences [5]. The other phase regards the decision process and includes further considerations, incorporating social and economic concerns as well as legal requirements and policy issues [1,6]. In other words, “risk analysis is only part of decision analysis and analysis is only part of any kind of management – risk management or otherwise” [2, p. 242].

2.3 Parts and content of the risk management process

The review of the main current approaches to risk in a wide set of environments, provided by the International Risk Governance Council IRGC [5, pp. 86-156], comes to the conclusion that although there is a lack of consistency in the use of terms, as well as different emphases placed on the parts of the risk management process, the basic processes involved in assessing and managing risks are to a great extent the same.

Thus, without dwelling on the terminology differences between the wide range of organisations and publications concerning risk management, the intention is to understand the logic and the function of the common process phases or else, as Hubbard proposed, a simplified risk management cycle. Necessary conditions of an informed risk mitigation is first to identify and then to assess risks. Although there are cases of easily understood risks that can be addressed apparently without great assessment efforts, in most situations there is a large number of risks, with different potential risk mitigation strategies but only a restricted availability of resources. For this reason, it is necessary to assess not only the initial risks but also the expected risk reduction if various measures were taken against their costs. In this way, as Hubbard underlines, “risk assessment appears prior to and as part of the selection of risk mitigation methods”. Once the mitigation options have been selected and implemented, they have to be monitored with the same manner and the risk management cycle is about to begin again [2, pp. 30-31].

3 RISK CLASSIFICATION SYSTEMS IN THE FIELD OF MUSEUMS

The publication of *The ABC Method: a risk management approach to the preservation of cultural heritage* in 2016 represents the updated version of the risk management practices developed by the Canadian Conservation Institute, the ICCROM, and the Netherlands Cultural Heritage Agency [7]. The manual, based on the experiences carried out in the field of museums since 1980 [8,9,10], is built around the five principal steps of a risk management process [11,12], and provides detailed explanations about tasks and activities for the implementation of each step.

Two aspects are of particular interest for the purpose of this study. The first one regards the use of frameworks “for thinking about risks in the identify, analyse and treat steps” [7, p. 69]. Five classification schemes are proposed based on “agents”, “types”, “stages”, “layers”, and "sources of knowledge".

The ten agents of deterioration are used to identify risks and serve as channels to organise all the scenario paths from hazards to adverse effects [7, pp. 70-72].

In terms of occurrence, risks can be classified in three practical types, i.e. rare events, common events, and cumulative processes, with the aim to "guide the risk discovery process, to guide the location of information during the analyse step, and to guide thinking during the treat step" [7, p. 73].

The analysis of risks according to the five stages of control – corresponding to preventive conservation (1. avoid sources of the agent, 2. detect the agent, 3. block the agent, 4. respond to the agent), disaster planning (5a. recover from the fast agent), and remedial conservation/restoration (5b. recover from the slow agent) [8] – ascertains the feasibility and the effectiveness of the risk treat options [7, pp. 75-76].

As for the six layers – region, site, building, room, fittings, packaging/support, and items – besides being useful for the analysis of the block stage of control, they organize possible sources of hazards and agents of deterioration, as well as they structure the knowledge and expertise needed for the analysis [7, pp. 77-78].

The last framework of the three sources of knowledge is closely related to the three types of occurrence. Regional statistics is the source of knowledge about the frequency/intensity of rare events; local knowledge (surveys) is the source for common events, the intensity of cumulative hazards, the five stages of control and the local layers; scientific and technical knowledge is the source for the sensitivity to cumulative processes and for most theories that can analyse risks [7, p. 79].

The second aspect concerns the quantification of risks. The two basic criteria, probability and consequences, have been formulated in order to place events and cumulative processes side by side and to include the relative importance/significance of the various items of the collection [7, p. 17]. The former becomes Frequency (for events) or Rate (for cumulative processes) and the latter is called Loss of value and is divided into two parts, the fractional loss of value to each affected item, and the items affected expressed as a percentage of the total value of the asset [7, p. 93]. The estimation of these three factors constitutes the basis for the comparison of risks.

Following the common practice in risk assessment of distinguishing between the technical components of risk analysis and the subjective components, i.e. the value judgements, the manual affirms the necessity to provide a clear description of the two stages in derivation of the loss of value to each affected item: the expected damage in technical terms and the impacts on value [7, p. 129]. As stated in the manual "comparing risks with different kinds of deterioration requires the adoption of a common scale to convert the predicted deterioration into predicted loss of value. This is the hard part of comparative risk assessment and the essential part. It links material science to cultural values" [7, p. 23]. In addition to the loss of value, criteria such as uncertainty, constraints, opportunities, or the cost-effectiveness of options and the cost of options can be assessed and used during the risk evaluation phase [7, pp. 134-138, 142].

4 RISK CLASSIFICATIONS SYSTEMS IN THE FIELD OF BUILT HERITAGE

4.1 Classifications based on "hazard" and "vulnerability" categories and levels

The first example taken into consideration is the Risk Map of Cultural Heritage developed by the Italian Central Restoration Institute (ICR) [13]. The division in three groups made by Risk Map attempts to the characterisation of the risks according to three hazard categories and the corresponding vulnerability aspects of the building elements that have to be considered. In detail, the three clusters defined, the environmental-air domain, the static-structural domain, and the anthropic domain, connect the three diverse nature of risk factors – i.e. the climatic/microclimatic and air pollutants risk factors, the geomorphological characteristics of the ground and of the subsurface, and the demographic/socio-economic dynamics – to the three different aspects of vulnerability defined by the material surface characteristics, the structural characteristics and the use/safety aspects of the building.

Even if the taxonomy is referred to the nature (climatological, geophysical, and anthropic) of risk factors and the building vulnerability aspects, we can notice that the two of the three types defined are equal to the types defined by Waller. Indeed, in the first category of rare/catastrophic risks we can link the static-structural domain, where the hazards considered are: seismic, landslides, floods, coastal dynamics, avalanches and volcanic, i.e. with low probability but severe effects, involving the structure of the building. In the third category of constant/mild-gradual risks we can associate the environmental-air domain characterised by threats, such as temperature, precipitation, wind, air humidity, pollution etc., that have cumulative effects on the surfaces of the building materials.

Another project that follows the same groups of risks with Risk Map is the European CHIC protocol [14]. In this case, the distinction between certain/long term and uncertain/rapid onset effects for the natural risks is clarified.

Similarly to the three types of risks defined in museum collections, they contribute to the identification of risks, they organise the knowledge and the expertise necessary for the analysis and finally guide thinking in the treat step. Moreover, this sort of classification, as Baer [15] explains, is significant in the risk management process. A rapid onset event with low probability may not justify preventive actions, whereas a slow acting agent that it is expected to affect with certainty the elements exposed may is a reason to take immediate action. On the other hand, the risk of a catastrophic event, characterised by a worrying rate of occurrence may necessitates a significant allocation of resources.

As for the measurement of risks, Risk Map considers three different detail levels according to the scale considered: territorial, individual, and local risk. The territorial risk is based on the hazard and exposure indicators related to the municipal area; the individual risk concerns the hazard indicator of the municipal area combined with the vulnerability of a single building; and lastly the local risk that relates the indicator of local hazard with the building vulnerability.

Recent developments of Risk Map tool concern the elaboration of a new evaluation model of seismic risk by updating the indicators of seismic hazard and vulnerability according to the new recommendations for the assessment and mitigation of seismic risk to cultural heritage approved in 2011 [16], as well as a proposal to adapt the tool to the characteristics of the buildings in historical centres [17].

4.2 Classification schemes based on "nature", "temporality", "scale" and "probability" of risk factors.

Another example of risk classification schemes for the built heritage is Dario Camuffo's work "Perspectives on risk to architectural heritage" [18], in which the author compiles a list of the major risk factors. He focuses on the problems related to the physicochemical decay of the buildings and discusses the gaps in our scientific and technological knowledge, the controversies over the interpretation of results, and the latest trends. At the end of the chapter proposes a classification of selected risk factors to cultural heritage. The risk factors are divided in two large groups, natural and anthropogenic and qualitative indications of "nature", "temporality", "scale", and "probability" are given.

With regard to the nature, risk factors are characterised mainly by a physical, chemical, or biological action. Concerning the temporality, they are separated in long term, medium term and rapid onset, while in respect of the scale, they can be local, regional, and global. As for the probability, risk factors vary from rare, infrequent and frequent events, to continuous cycles and continuous. Although the criteria and the various categories proposed in this table by Camuffo are not new, on the contrary they are commonly used in the conservation field, this work gains importance because of its holistic and systematic approach. Indeed, the organisation of the major threats to which is exposed built heritage and their qualitative characteristics contributes to their understanding and their management.

4.3 Classification schemes based on "cause-effect" relationships, "building materials", "building elements", and "building typologies"

Another common risk classification scheme in the field of build heritage is the consequence-based approach. In fact, thanks to several efforts matured in architectural preservation field, guided procedures for the analysis of the decay/damage have been introduced in national and international recommendations. The data collected from different sources, such as literature, in situ investigations, and laboratory simulation tests has improved our knowledge on the possible decay/damage causes and their consequences.

Indicative examples are the *Damage Atlas* published in 1998 [19] and the subsequent development of a *Structural Damage Atlas* in recent years [20]. The first gathers and schematize into relations between damage types, causes and deterioration processes the current knowledge of the environmental effects on brick masonry deterioration by drawing attention on the complex interaction of different materials and different boundary conditions [21]. The second focuses on the mechanical behaviour of brick- and stonework masonry under different actions, caused by sudden events such as earthquakes, floods etc. or by long term phenomena such as soil settlement, heavy loads and lack of maintenance, and forms a basis for the definition of typical structural damage patterns.

Without going into details, the damage classification concerning the structural behaviour and the failure mechanisms of the building elements takes into account not only the construction materials, but also the different building typologies and the role of the various structural elements and their connections.

4.4 Classification schemes based on the "combination of risk factors" and the "risk level change" in the course of time

During the last years, the studies on the effects of the environmental factors on the cultural heritage have drawn attention to the issues related to climate change and the new pressures that will be caused by variations in temperature and precipitation, changes in soil conditions, groundwater and sea level, and extreme climatic events.

The Noah's Ark project has developed quantitative models for the global climate change impacts on the deterioration of different heritage materials on European geographical scale [22]. The results of the research project, gathered in different types of maps, correspond to the methodological approach adopted. Firstly, "climate maps" were elaborated by selecting the traditional climate parameters, both meteorological and pollution, relevant to cultural heritage. Estimations were carried out by taking into account different future scenarios and three periods, recent past, near future and far future. In order to obtain the most critical synergetic effects for the historic building materials, the previous climate maps were combined and specific "heritage climate maps" were produced, representing the advancement of the conservation science to adapt the classic meteorology to the needs of conservation [18]. The next step regarded the quantitative expression of damages or else the development of damage functions for the different building materials, based on different information sources, such as field data, literature survey, and laboratory investigations. The results were translated into "damage maps" which in their turn were summarized in "risk maps", showing the type of risks that are likely to increase or decrease in the different regions of Europe.

Among the various classification schemes used in this example, two of them stand out. On the one hand, the examination of synergetic effects based on the combination of different risk factors is necessary for the identification and the assessment of risks for different materials .On the other, the reflection on the risk level change in the course of time becomes useful for the understanding of the priorities and the need of measures.

4.5 Classification schemes based on the "building elements relationships" and the "dependency of risks"

The need for improving management tools has given rise to regular inspection surveys, to systematic monitoring, to periodic maintenance and risk assessment practices as the most proper preventive strategies, e.g. Monumentenwacht organisations in different European countries, Maintain our Heritage in UK, Preventive and Planned Conservation in Italy, the Heritage Care project in South-West Europe, etc. [23,24,25,26,27]. Indeed, the European standard *Conservation of cultural property – Condition survey of immovable heritage* [28] integrates the risk assessment with the condition assessment and represents an attempt to implement preventive strategies.

In the first draft of the standard, despite the consideration of relevant aspects related to the analysis of risks during the phase of assessment, the identification of the related measures was not based on the previous analysis or rather it was not based in an explicit way. Indeed, the activities of condition and risk assessment were not separated and the classification of measures was linked directly to the condition classes. The final version of the standard, approved in 2012, has resolved the previous ambiguities firstly by pointing out the difference between condition and risk assessment, and secondly by setting up a classification of urgency categories, i.e. urgent and immediate, short term, intermediate term, and finally long term, connected to the risk analysis. This sort of classification, based not only on the level of risk but also on the risk level change in the course of time (or the velocity of damage progression), as it has already been mentioned in the previous paragraph, is essential for the planning of the necessary measures.

Another important aspect of the risk analysis that the document proposes is the relationships between the building components. In fact, the description of the elements interactions is fundamental for the understanding of the unity and the complexity of the building system. For instance, the four basic interaction modalities between the various building technological elements suggested by the Italian guidelines for the conservation plan contribute to the better understanding of the effects that could be caused by the changes of the conditions of the elements in the course of time and in relation with the use of the building [26, pp.41-42]. Another example is the classification of typical seismic damage of the immovable artistic assets according to their connection with the structural elements proposed by the PERPETUATE project [29].

4.6 Classification based on "risk reduction measures", their "control level" and the "time of action"

The most important international organizations, such as UNESCO, ICOMOS, ICCROM, Council of Europe, etc., have strengthened their activities to develop operative methods for an overall prevention and mitigation strategy for the protection of cultural heritage against disasters. For example, the *Risk-Preparedness Manual for World Cultural Heritage* in 1998 [30] and *Between Two Earthquakes* in 1987 [31] are two of the first publications in a series of handbooks that is still being added to and updated in view of current concerns related mainly to the risks of climate change faced by cultural heritage.

The planning framework proposed in these manuals usually takes into account three elements: the action time, i.e. the preparedness (before), the response (during), and the recovery (after) phases; the typology of risk reduction measure; and the control level or else the different role of public institutions and private owners.

Apart from a guide to the identification and organisation of the measures that can be taken against disasters, this scheme could be also used to classify the risks to which built heritage is exposed according to the feasibility/effectiveness of implementing the various typologies of measures [32,33]. What is more, this classification not only indicates the prevalent strategies for the prevention/mitigation of risks but defines also the priorities for their assessment.

5 RISK CLASSIFICATION SCHEMES PROPOSED IN OTHER FIELDS

The most common approaches to the classification of risks employed in other fields, e.g. in insurance and financial industry, in the safety engineering field, or in health and environmental sector, are based on causal agents, risk events, and their potential consequences.

A different approach was developed by WBGU [34], and reviewed later by IRGC [5]. It is based on the concept of systemic risk, i.e. draws attention to the interdependencies and interactions between environmental, social, financial, and economic risks and opportunities. As Klinke and Renn [35] argue there are two key elements that characterise this approach, firstly the extension of factors that should be taken into consideration when managing systemic risks and secondly, the inclusion of analytic-deliberative processes in the regulatory framework.

In detail, the analysis increases the number of criteria, from two– the two classic components of risk, probability and magnitude of damage– to eight, by adding other physical and social impact categories, i.e. the incertitude, the ubiquity, the persistency, the reversibility, the delay effects, and the potential of mobilization.

Considering these criteria, four risk clusters have been identified, according to the different states of knowledge for each risk, distinguishing between 'simple', 'complex', 'uncertain' and ‘ambiguous’ risk problems. “The characterisation of a particular risk depends on the degree of difficulty of establishing the cause-effect relationship between a risk agent and its potential consequences, the reliability of this relationship and the degree of controversy with regard to both what a risk actually means for those affected and the values to be applied when judging whether or not something needs to be done about it” [5, p. 12]. Based on these risk categories different strategies have been defined for both risk assessment and risk management, as well as about the level and the form of stakeholder participation, supported by suitable methods and tools.

The importance of this classification lies, on the one hand, in the acknowledgement of social, political and cultural contexts, as well as of individual and cultural value judgments, beyond the level of risk, that influence the acceptability/tolerability evaluation of risks (34, p. 29; 5, p. 37]. On the other hand, it allows flexibility in regard to the appropriate position of decision-making concerning the acceptability/tolerability of a risk by assisting assessors and managers in assigning, or dividing this judgement task through the consideration of its two distinct components, the evidence-based and the value-based component [5, pp. 37, 40].

These two factors become relevant to the management of built heritage. The concern about the broader context of the built heritage and their coevolutive relationship, as well as the maturing of sustainable principles, and the necessity of a long term perspective [36] can be reflected by the above systemic approach.

6 CONCLUSIONS

The study of various examples of risk classification schemes draws attention to the different criteria on which they are based and the variety of the risk aspects analysed, useful in diverse ways in the risk management process.

Specifically, the analysis indicates that two main groups can be distinguished according to their utility within the risk management process. The first one contributes mostly to the identification and the assessment of risks, and the second one is associated mainly with the management phase. If in the first group, criteria such as nature, scale, timing, probability/frequency, severity, relations and consequences of risk factors play a part in establishing and/or estimating cause-effect relationships, in the second group, the criteria suggest priorities, strategies, and their efficiency.

In fact, these sorts of classifications have been already applied in an organised manner to the risk management methodology elaborated by the museum sector as it is shown in the example taken into consideration here. Concerning the built heritage conservation, it can be noticed that the various classification schemes proposed and analysed have not been incorporated into a systematic risk management methodology.

In this perspective, the overview provided in this paper represents an attempt to frame a more methodical and holistic approach to the built heritage risk management. In other words, the combination of different classification schemes could be integrated with the various phases of risk management in order to respond adequately to the diverse needs of the process.

However, the different classification schemes analysed in this study cannot be considered exhaustive. The examples that are presented here cover basic and generic classes of risk and they are indicative. According to the particularities of each case, the classifying criteria can be adapted to the specific needs and more precise categories can be formed. Thus, the methodological approach suggested depends not only on the different needs of the process but also on the needs of the specific built heritage case.

Table 1: Different risk classification schemes according to the selected criteria on which they are based and their utility/scope within the risk management process

Selected criteria	Risk classes	Utility
Risk factors nature	Cause based or mechanism based classes	Risk identification, risk assessment, risk management
Scale	Local, regional, global	
Temporality	Long term, rapid onset	
Probability/Frequency	Rare events, common events, cumulative processes	
Hazard and vulnerability categories	Environmental-air, static-structural, and anthropic domain	
Damage mechanism, building elements characteristics, building typologies	Consequence based classes (decay/damage types)	
Combination of risk factors	Synergetic effects-based classes	
Building elements interactions Relationships of risks	Dependency based classes	
Probability, consequences (direct and indirect, tangible and intangible) Hazard level, exposure level, vulnerability level	Risk level based classes	Risk assessment
Risk level Risk level, constraints, opportunities Risk level, risk level change in the course of time	Priority based or urgency based classes	Risk management
Reduction measure, response level, action time Feasibility/effectiveness/cost-effectiveness of measures Knowledge characterisation	Management strategy based classes or management strategy efficiency based classes	

REFERENCES

[1] Ball, D.J. The evolution of risk assessment and risk management: a background to the development of risk philosophy, *Arboricultural Journal* (2007) **30**(2): 105-112.

[2] Hubbard, D.W. *The failure of risk management: why it's broken and how to fix it*. New Jersey: John Wiley & Sons (2009).

[3] Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S.L. and Keeney, R.L. *Approaches to Acceptable Risk: A Critical Guide.* Work Performed for U.S. Nuclear Regulatory Commission under NRC Interagency Agreement 40-550-75. Oak Ridge National Laboratory, operated by Union Carbide Corporation for the Department of Energy (1980).

[4] Kaplan, S. and Garrick, B.J. On the quantitative definition of risk. *Risk Analysis* (1981) **1**(1).
[5] Renn, O. (ed.), *White Paper on Risk Governance: Towards an Integrative Approach*. Geneva: International Risk Governance Council (2005).
[6] Watt, J.M. The management of risk with respect to cultural heritage – a case study, *Arboricultural Journal* (2007) **30**(2): 175-185.
[7] Michalski, S. and Pedersoli J.L. (eds), *The ABC Method: a risk management approach to the preservation of cultural heritage*. Ottawa: CCI, ICCROM (2016).
[8] Michalski, S. An overall framework for preventive conservation and remedial conservation. In: *ICOM Committee for Conservation, 9th triennial meeting, Dresden, German Democratic Republic, 26-31 August 1990, preprints*, ICOM Committee for Conservation (1990), pp. 589-591.
[9] Waller, R. Conservation risk assessment: a strategy for managing resources for preventive conservation. *Studies in Conservation* (1994) **39**(sup2): 12-16.
[10] Waller, R. Risk management applied to preventive conservation. In: C.L. Rose, C.A. Hawks, H.H. Genoways (eds), *Storage of natural history collections: A preventive conservation approach*, New York: Society for the preservation (1995), pp. 21-27.
[11] Joint Standards Australia / Standards New Zealand Committee OB-007, *Risk Management*, AS/NZS 4360 (2004).
[12] ISO International Organization for Standardization, *Risk Management*, ISO 31000 (2018).
[13] Accardo, G., Giani, E. and Giovagnoli ,A. The Risk Map of Italian Cultural Heritage, *Journal of Architectural Conservation* (2003) **9**(2): 41-57.
[14] eu-chic.eu. Eu-CHIC project official website. [online] Available at: http://www.eu-chic.eu/ [Accessed Oct. 2019].
[15] Baer, N.S. Assessment and management of risks to cultural property. In N.S. Baer, C. Sabbioni, A.I. Sors (eds), *Science, Technology and European cultural heritage, proceedings of the European Symposium, Bologna, Italy 13-16 June 1989*, Luxembourg: ECSC-EEC-EAEC (1991), pp.27-36.
[16] Cacace, C. and Donatelli, A. Carta del Rischio del patrimonio culturale: studio sulla vulnerablità e pericolosità sismica del patrimonio culturale in Sicilia e Calabria. In S. Della Torre and M.P. Borgarino (eds), *Proceedings of the International Conference Preventive and Planned Conservation, Monza, Mantova - 5-9 May 2014, Protezione dal rischio sismico*, Milano: Nardini editore (2014), pp.107-118.
[17] Cacace, C. and Fiorani, D. Centri storici, vulnerabilità, rischio e gestione della conservazione. Una proposta d'implementazione dello strumento Carta del Rischio. In S. Della Torre and M.P. Borgarino (eds), *Proceedings of the International Conference Preventive and Planned Conservation Monza, Mantova - 5-9 May 2014, Protezione dal rischio sismico*, Milano: Nardini editore (2014), pp. 119-128.
[18] Camuffo, D. Perspectives on risks to architectural heritage. In: N. S. Baer and R. Snethlage (eds), *Saving our architectural heritage: the conservation of historic stone structures*, New York: John Willey &Sons Ltd. (1997), pp. 63-92.
[19] Franke, L., Schumann, I., van Hees, R., van der Klugt L, Naldini. S., Binda, L., Baronio, G., Van Balen, K. and Mateus, J. *Damage Atlas - Classification and Analyses of Damage Patterns found in Brick Masonry*. Project EV5V-CT92-0108, Research report No 8, Volume 2, Stuttgart: Fraunhofer IRB Verlag (1998).

[20] Binda L., Saisi A., de Vent, I.A.E., Van Hees, R.P.J. and Naldini, S. Structural Damage in Masonry: Description and interpretation of crack patterns as basis for finding the damage causes. *Restoration of buildings and monuments, Bauinstandsetzen und Bauenkmalpflege* (2010) **16**(2), pp. 1-22.
[21] Van Hees, R., Binda, L., Van Balen, K. and Naldini, S. Expert system for evaluation of deterioration of ancient brick masonry structures. *The science of the Total Environment* (1996) **189/190**, pp. 247-254.
[22] Sabbioni, C., Brimblecombe, P. & Cassar, M. (eds), *The atlas of climate change impact on European cultural heritage: scientific analysis and management strategies*. London, New York: Anthem Press (2012).
[23] Van Balen, K. and Vandesande, A. (eds), *Innovative built heritage models.* London: Taylor and Francis Group (2018).
[24] *Journal of Cultural Heritage Management and Sustainable Development* (2018) **8**(2), Special Issue: Preventive and planned conservation approaches for built heritage management.
[25] Dann, N. Planned and preventative conservation and England: experiences, opportunities and requirements. In: *Preventive and planned conservation: proceedings of the international conference. Vol 4: Metodi e strumenti per la prevenzione e la manutenzione, Monza - Mantova, 5-9 May 2014*, Firenze: Nardini (2014), pp. 1-10.
[26] Della Torre, S. (ed.), *La conservazione programmata del patrimonio storico architettonico. Linee guida per il piano di manutenzione e consuntivo scientifico*. Milano: Guerini & associati (2003).
[27] Moioli, R. and Baldioli, A. *Conoscere per conservare. Dieci anni per la conservazione programmata*. Quaderni dell'Osservatorio, 29. Milano: Fondazione Cariplo (2018).
[28] CEN/TC 346 – Conservation of Cultural Heritage. *Conservation of cultural property – Condition survey of immovable heritage*, EN 16096 (2012).
[29] Abbas, N., Calderini, C., Cattari, S., Ginanni Corradini, R., Lagomarsino, S., Marghella, G., Piovanello, V., and Rossi, M. PERPETUATE FP7 - Theme ENV.2009.3.2.1.1 – ENVIRONMENT Grant agreement n°: 244229, Deliverable D4 (2010), pp. 78-94.
[30] Stovel, H. *Risk preparedness: a management manual for world cultural heritage*. Rome: ICCROM (1998).
[31] Feilden, B. *Between two earthquakes: Cultural property in seismic zones*. Rome, California: ICCROM, Getty Conservation Institute (1987)
[32] Della Torre, S. The management process for built cultural heritage: preventive systems and decision making. In: K. Van Balen, A Vandesande,. (eds), *Innovative Built Heritage Models*. London: Taylor and Francis Group (2018), pp. 13-20.
[33] Presidenza del Consiglio dei Ministri (PCM), Struttura di Missione Casa Italia. *Rapporto sulla Promozione della sicurezza dai Rischi naturali del Patrimonio abitativo* (2017).
[34] WBGU, German Advisory Council on Global Change, *World in transition. Strategies for managing Global Envirinmental Risks. Annual Report 1998*. Berlin: Springer (2000).
[35] Renn, O., and Klinke, A. Systemic risks: a new challenge for risk management, *EMPO reports* (2004).
[36] Della Torre, S. A coevolutionary approach to the reuse of built cultural heritage. In: G. Biscontin, G. Driussi, (eds), *Il patrimonio culturale in mutamento. Le sfide dell'uso*. Venezia: Arcadia Ricerche (2019), pp. 25-34.

Kerakoll is the international leader in the GreenBuilding sector, providing solutions that safeguard the health of both the environment and the people.

The company mission is embrace and promote GreenBuilding as the new low environmental impact approach to building and promote higher quality homes around the world through the use of eco-friendly building materials and innovative solutions.

Since 1968 – when the Group was founded in Sassuolo– Kerakoll has been pursuing a clear course of development in Italian and international markets for building materials, that has taken the company to the forefront of the GreenBuilding industry and to a level of technological supremacy famous around the globe.

S.T.A. DATA,founded in 1982 by Adriano Castagnone, civil and structural engineer since 1978, and pioneer of scientific software for structural engineering, is composed of more than 20 people, all highly qualified professionals. Our aim is to offer software for structural calculation that alallow designers to face everyday work with simplicity and effectiveness.

S.T.A. DATA offers 3Muri Project, developed specifically for masonry.

In fact, it is not a generic Finite Element software adapted for masonry structures; 3Muri Project was born from the specific research for these structures and captures all the characteristics to obtain a safe and reliable calculation of historical, exhisting and new buildings.

IRS is a smart Engineering, Research and Development company founded by a group of engineers in 1993. IRS Structural Health Monitoring division designs, develops and integrates automated systems for mechanical and structural monitoring. Thanks to technological innovation, advanced modeling and design as well as professional production and after sales service provide a complete suite of structural health monitoring solutions. Monitoring version are both portable version for laboratory tests and one shot structural assessments and long term and in situ applications like historical sites, buildings, bridges, dams and tunnels. IRS is part of a group of companies including Measureit, with whom provides consultancy and sales of precision sensor and data acquisition systems.

SUMMARY

PRESENTED SESSIONS