GUIDELINES FOR THE ANALYSIS, CONSERVATION AND STRUCTURAL RESTORATION OF ARCHITECTURAL HERITAGE

SEPTEMBER 2024

ICOMOS / ISCARSAH

INTERNATIONAL SCIENTIFIC COMMITTEE FOR ANALYSIS AND RESTORATION OF STRUCTURES OF ARCHITECTURAL HERITAGE

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1 GENERAL CRITERIA

1.1 Aims of the study of historical structures. Purpose of the guidelines

The main purpose of the study of historical structures lies in their optimal conservation and transmission to future generations. Since historical structures have heritage value in themselves, their conservation involves not only the assurance of their structural performance, but also the preservation of all tangible and intangible values that contribute to their authenticity and cultural dimension. The structure constitutes an essential part of the building's cultural legacy.

Any intervention should, as far as possible, respect the structure's cultural value and the historical evidence that it provides. Therefore, the study and conservation of a historical structure must consider and optimally reconcile the structural requirements with those related with its preservation as a cultural resource. Both aspects must be considered in any decision on structural interventions.

The present Guidelines are intended to provide criteria and assistance for the study and intervention on heritage structures. They are based on the premise that a combination of both scientific and cultural insight, in addition to the necessary technical knowledge of all experts involved, is indispensable for the study and care of the built cultural heritage. The Guidelines are also based on the understanding that, within such a multidisciplinary approach, structural engineering provides the technical support necessary to obtain the expected result, namely the safeguard of the structure as a whole, with the lowest possible impact on its heritage values.

[1] *Approved in the ISCARSAH Annual General Meeting, Sinaia, Romania, 25 September 2024.*

The Guidelines are also intended to provide guidance for the application of more fundamental documents such as the ISCARSAH Principles for the Analysis, Conservation and Structural Restoration of Architectural Heritage ratified by the ICOMOS 14th General Assembly in Victoria Falls, Zimbabwe in 2003, and Annex I on Heritage Structures of ISO 13822:2010.

In addition to the study of individual monuments, the Guidelines are also concerned with modest works from the past that may attain cultural significance because of their contribution to the identity of an urban or rural setting. This includes the case of groups of buildings with common construction features and meaningful cultural value as a cluster, such as buildings in historical urban centres. In turn, the Guidelines are expected to be applicable to structures built according to all construction technologies from the more distant and more recent past, including (among other possible materials) earth and masonry, timber, iron and steel, and concrete structures.

The Guidelines are addressed to the entire multidisciplinary team under the guidance of architects and engineers, while being also expected to be useful to the authorities and decision-makers with responsibility in the conservation of the built cultural heritage. The Guidelines have been prepared to assist the multidisciplinary team while also facilitating seamless communication and collaboration among experts, stakeholders and decision-makers participating in the conservation process.

The Guidelines embrace both environmental impact reduction and circular economy principles. While conservation inherently contributes to sustainability by preserving historical materials, its benefit can be amplified by using recycled or locally sourced materials, minimizing waste, and extending lifecycles. Additionally, enhancing the resilience of historical structures against climate change (through measures such as flood protection and improved stability against temperature and humidity changes) further strengthens the environmental commitment by addressing future threats.

1.2 Heritage values and character-defining elements

The entire multidisciplinary team, including architects, archaeologists, engineers, historians and other experts, should be responsible for identifying and defining the heritage values in a historical structure.

As stated by the Nara Document (1994), conservation of cultural heritage in all its forms and historical periods is rooted in the values attributed to the heritage. Therefore, the understanding and the respect for authenticity plays a fundamental role in all studies on cultural heritage. Applying these concepts to a structure requires a previous investigation to identify its character-defining elements, i.e., those features that contribute to its heritage values and authenticity. The Nara Document (1994), the Venice Charter (1964) and the ICOMOS / ISCARSAH Principles (2003) provide guidance on determining such character-defining elements.

Among the tangible character-defining elements are:

- The geometry, including the shape, spatial configurations and formal design.
- The materials and fabrics.
- The overall structural organization.
- The construction details and connections.
- The location and setting (either urban or rural).

- Significant historical modifications (such as additions produced in different historical periods).
- Imperfections and damage, provided that they do not compromise the safety requirements or the structure's durability.

Among the intangible character-defining elements are:

- The construction traditions and techniques.
- The structural concepts and the resisting mechanism.
- The original use and function.
- The evidence of past knowledge, practices, culture, cultural associations, technology and association to historic events.
- The spirit and feeling conveyed by the historic structure.

Such character-defining elements contribute to at least four categories of heritage values, respectively corresponding to:

- Aesthetic values, relative to aspects such as the form and decoration in the exterior and interior.
- Historical values, relative to the symbolism and function of the building.
- Technical values, relative to the structural concepts, the construction techniques and the materials.
- Social values, relative to aspects such as the cultural memory, the continued use of the historic building, its educational potential and the economic dimension of the conservation programme.

It is recognized that the judgments about heritage values may differ from one culture to the other. For instance, in some geographic areas, substitution of structural members may be regarded as an approach consistent with the history and tradition of maintenance. In these cases, keeping alive traditional construction practices may be prioritized over the conservation of the original material.

From the point of view of conservation, foundations are not different from the rest of the structure and should be evaluated and, if necessary, repaired or strengthened taking into consideration their authenticity and heritage values.

The design of the intervention should follow an optimization process oriented to select the best possible solution. The objective of such optimization process is to identify a minimum necessary intervention attaining the requested structural performance with the minimum possible impact on the heritage values. The present document is largely devoted to provide guidance on the concepts and approaches that can be adopted to attain this aim.

1.3. Minimum intervention

A minimum intervention can be defined as a set of structural measures of high technical quality that optimally combines compliance with structural requirements with the best possible protection and enhancement of the heritage values. As indicated in section 3.1, minimum intervention must satisfy the structural requirements necessary for the protection of human life, while also paying attention to environmental impact and cost effectiveness.

Any intervention on a heritage structure entails, to some degree, positive and/or negative impact on the heritage values. Therefore, the final decision on the appropriate intervention should be taken on the basis of an optimization approach based on the evaluation (even if only qualitative) of such impact.

This definition permits a formal or mathematical interpretation where the optimal solution is obtained by minimizing an objective function subject to defined constraints. The objective function represents the intervention's impact on heritage values, and the constraints embody the structural requirements essential for ensuring people's safety and protecting valuable immovable cultural and artistic contents. Section 3 elaborates on this understanding in greater detail. It must be highlighted, however, that the values to be considered in this evaluation are not quantitatively comparable, which hinders the possibility of a purely quantitative or unidimensional analysis. A satisfactory solution can be reached through multicriteria analyses combining qualitative and quantitative criteria by using a logic tree decision.

Prioritizing minimum interventions implies rejecting solutions that go beyond what is essential for safeguarding the building, its artistic contents, and human safety. In essence, such interventions should rely on repair and/or strengthening methods that cause the least possible alteration to the structural features and resistance mechanisms. As a general rule, no actions should be undertaken without demonstrating that they are indispensable. In this respect, a thorough documentation of the structure (including its foundation soil and environmental conditions) may provide (i) a higher level of knowledge regarding resisting mechanisms and actions, (ii) data for the calibration of numerical models, and (iii) a solid basis for the determination of appropriate solutions complying with the concept of minimum intervention.

In addition to preserving the structure's authenticity, excessive unnecessary alterations are not advisable because the modified structure may develop a response difficult to predict, especially in the case of an earthquake or other extraordinary actions, with potential undesirable consequences. The study of the impact of past earthquakes on historical structures has shown that some past interventions (as, in some cases, the replacement of wooden floors with reinforced concrete slabs) aimed to improve the original structural behaviour were inadequate and may even have caused dangerous effects on the structural response. Conversely, interventions based on respectful and efficient solutions compatible with the original structure (as the insertion of ties or the improvement of connections between vertical and horizontal elements in buildings) have shown to provide a more satisfactory response. The minimum intervention approach is, in many cases, also the most efficient and reliable one from the point of view of the structural performance.

Furthermore, solutions causing a significant alteration may be difficult or impossible to remove, therefore compromising later improvements or future new interventions (which is in contradiction with the criteria of removability and re-treatability presented in section 4.1).

1.4 Limitations of codes and conventional methods. Proposed approach

Understanding the response of historical structures is often a challenging endeavour requiring sufficient knowledge on the nature of the materials (namely masonry, timber, earth, concrete, iron, steel, etc.), the variability of the material properties, the internal morphology of the structural members, the complex geometries and construction details, the influence of historical actions and the impact of past interventions.

Due to their nature and history, the structures of architectural heritage present a number of challenges in diagnosis and conservation that limit the applicability of legal documents (codes and building standards) not specifically oriented to them. The same can be said about conventional calculation methods not specifically oriented to the study of heritage structures.

The uncritical application of available codes and standards not intended for heritage structures may lead to erroneous conclusions on their structural performance and intervention needs. It must be recalled that most codes are not meant to describe the real behaviour and safety condition of historical structures, and are based on hypotheses and models that may be inappropriately applied to them. For example, the strict application of seismic and geotechnical codes can lead to drastic and often unnecessary measures that may fail to consider the real structural response.

It is noted that adopting a too conservative approach, as a way to compensate for insufficient information, may be inadequate in the case of heritage structures, as it may induce excessive and unjustifiable interventions in terms of loss of authenticity and cultural value.

It is also noted that, in some cases, new uses intended for historical structures may be inappropriate because they may require an excessive intervention involving a significant alteration of the original structure. In these cases, alternative uses more compatible with the existing original construction should be envisaged in order to respect its heritage values.

In the strengthening of historical structures, in some cases it may be acceptable not to fully enforce the structural requirements conventionally prescribed by standards oriented to modern structures. The conditions under which a reconsideration of the structural requirements may be acceptable is discussed in section 3.1.

In order to retain the principle of minimum intervention and to relate the remedial measures to the actual behaviour, the study of historic structures requires the adoption of a flexible and broad approach strongly based on the scientific method. The approach herein proposed combines and integrates qualitative and quantitative evidence provided by a set of complementary activities. These activities are:

- Historical research, based on the study of the historical features and response of the structure through the investigation of documentary sources.
- Architectural and structural inspection (including surveys and investigations) consisting in the characterization of the current condition and properties of the materials and structure, including its foundation and its environment.
- Monitoring, based on the observation of the response of the structure over a period of time.
- Structural analysis, consisting of the quantification of the response of the structure by means of a sufficiently accurate and calibrated structural model. Calibration and validation of the model is done by comparison with empirical information provided by historical research, inspection and monitoring according to the approach described in section 3.7.

While historical research provides mostly qualitative evidence, monitoring and structural analysis supply mainly quantitative information. Inspection provides both qualitative information (types of materials and damage) and quantitative information (geometry, mechanical properties, crack patterns and widths, deformations, etc.).

Within this wide approach, structural engineering provides the technical and scientific support necessary to reach the conclusions on the structural condition and the adequate intervention strategies. Nevertheless, and given the wide expertise needed to cover all the necessary knowledge, the studies should be carried out within multidisciplinary teams involving different experts (engineers, architects, archaeologists, historians, geophysicists, chemists and other), thus enabling to reach a common decision on the optimal interventions.

It should be noted that the approach described above is not necessarily a linear procedure but often an iterative one in which methods and conclusions may need to be reconsidered according to a multicriteria optimization strategy.

1.5 Phases of the study

The study of a historical construction involves four subsequent phases corresponding to (1) anamnesis, (2) diagnosis and assessment of structural performance, (3) therapy and (4) control.

The first phase, **anamnesis**, includes all the historical, architectural and structural data acquisition campaigns and all the investigations (laboratory, field and other) necessary to derive final conclusions on diagnosis, assessment and therapy.

The second phase, **diagnosis and assessment of structural performance**, is oriented to identify the causes of damage and decay, and to characterize the structure's conservation condition. This phase also involves the evaluation of performance of the structure in its current state and the identification of the intervention needs.

The third phase, **therapy,** involves the design of alternative intervention schemes and the assessment of their efficiency, the identification of the optimal solutions and the detailed definition of the intervention strategies with the necessary design details and specifications of materials and techniques.

The fourth phase, **control,** includes the necessary quality control checks and monitoring campaigns to be implemented for verification purposes before, during and after the execution of the intervention. It also includes a detailed maintenance plan.

The four phases must be logically and methodologically consistent. In particular, structural performance verification and design of the intervention must be strictly based on the conclusions resulting from the diagnosis and the assessment of the structure at its current state. Moreover, the four phases should be undertaken using similar activities and methods. For instance, the monitoring and structural analysis methods used for assessment are also useful for the verification of the response of the structure after intervention.

If these stages are not performed and linked correctly, the resulting decisions on the intervention may not satisfactorily address the real problems of the structure. Poor judgement may result in either conservative (and therefore heavy-handed conservation measures) or insufficient actions (leading to inadequate performance levels). Since the entire process leading to the definition of an intervention requires a wide range of expertise, the collaboration among the different experts, in the frame of the multidisciplinary team, is necessary across the four phases. At all the stages, decisions should be reached within the multidisciplinary team.

The process that leads to the minimum intervention is an iterative one with a number of possible repetitions across the four phases. The process is based on a continuous critical appraisal of the outcomes of each phase. This is illustrated in the flowchart presented in Figure 1.

The flowchart in Figure 1 shows that the process of formulating a diagnosis is a progressive one, which is determined by the availability of data, collected during the anamnesis phase, the reliability of the results obtained during preliminary analysis and the constant assessment of the level of knowledge acquired. This progressive approach allows balancing the demand for data (which is costly and time consuming) with the need for consolidated knowledge, by evaluating the level of confidence achieved by the team in formulating a diagnosis.

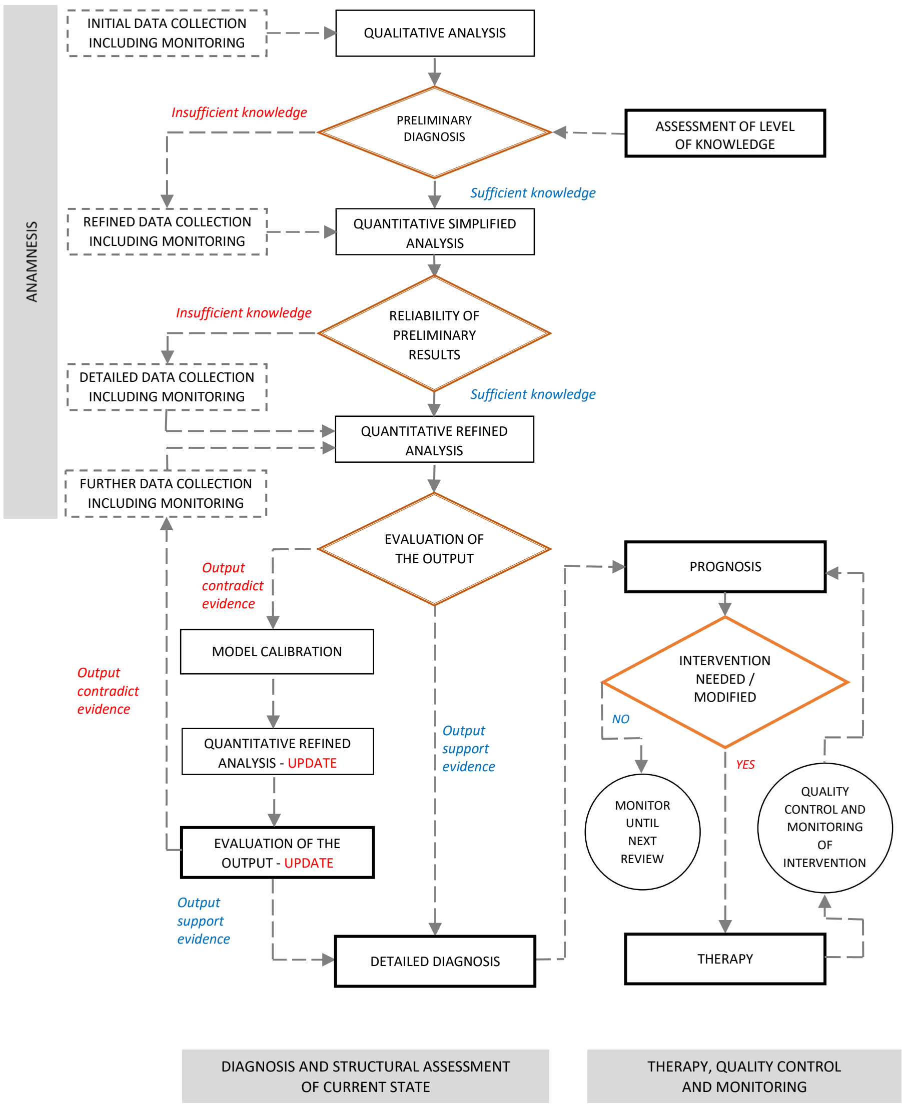

Figure 1. Flowchart including the four phases of the structural conservation process.

Sufficient reliability of the preliminary analysis enables performing the refined quantitative analysis which is then evaluated against the evidence. When the evidence supports the output of the refined analysis, it is possible to proceed with the detailed diagnosis. Otherwise, it is recommended to calibrate the model, update the refined analysis and, then, proceed with the detailed diagnosis, in case of satisfactory output results. In case of unsatisfactory output results, it is necessary to collect more data ("further data collection") and repeat the procedure.

Once such diagnosis is determined and agreed upon, to continue the medical analogy, a prognosis can be formulated, i.e. a forecast of the likely outcome of the current situation, leading to the decision on whether it is appropriate to intervene and therefore the definition of the therapy. This phase is also iterative, because often the effectiveness of the therapy can only be fully determined during its implementation and may need adjustments and refinements. It may also occur that while the intervention is in progress, other issues are unearthed and the prognosis shall be reviewed and modified. During this iterative process the continuous monitoring of the state of the structure and its evolution is a critical support to decision making.

Anamnesis, diagnosis and assessment of the structure at its current state, therapy and control are discussed in sections 2, 3, 4 and 5, respectively.

1.6 Structural analysis

The purpose of structural analysis is the characterization of the response of the structure under a variety of conditions and actions. This characterization involves results on stresses, strains, displacements and reactions. Non-linear analysis may also provide results on damage (cracking in tension, crushing in compression, etc.) and reproduce detailed loading processes across the initial, service and ultimate ranges; specifically, it may be used to analyse the ultimate capacity of the structure under different actions. Construction sequence and building phases can be included in the simulation.

Structural analysis can be used across all the phases of the study. During the anamnesis phase, preliminary structural analysis may be used to identify the most important vulnerabilities and thus guide the investigation and research program.

During the diagnosis and assessment of structural performance, structural analysis can be utilized to simulate the response of the structure under a variety of past or future actions. While simulating past actions may provide insight on the causes of existing damage, simulating future ones may contribute to characterize the sufficiency or deficiencies of its current structural performance.

Finally, during the therapy phase, structural analysis is performed in order to simulate the behaviour of the structure with alternative intervention schemes and assess their distinct performance and efficiency. Moreover, numerical analyses provide action-effects that are used to design the interventions and do all necessary verifications.

Most modern approaches to structural analysis are based on an accurate numerical simulation of the response of the structure. In addition, some classical approaches based on the equilibrium of forces or kinematically admissible mechanisms, such as limit analysis, can be successfully utilized for the characterization of the ultimate performance and collapsing mechanisms.

Whatever the type of approach utilized, structural analysis is always based on a certain model of the structure. The model has to be chosen and constructed to provide a satisfactory description of all the relevant mechanical and resisting phenomena characterizing the response of the structure. The hypotheses and assumptions considered in the elaboration of the model must be made explicit and must be taken into consideration in the interpretation of the results.

There are two main sources of uncertainty in a structural model:

- First, models are necessarily based on mathematical theories to describe the mechanical and resistant nature of the structure and the materials. The ability of a model to accurately describe the structural response will largely depend on the representativeness and realism of the adopted formulations.

- Second, data are always limited and liable to uncertainty. Normally, the amount of data available are insufficient for a complete definition of a model. The uncertainty and data insufficiency may be seen in both structural parameters and actions. The lack of information requires assumptions or extrapolations on certain structural features (such as the distribution of materials or the internal morphology of structural members).

Due to these uncertainties, models must be always calibrated using the available evidence on the performance and condition of the structure. The necessary evidence can be provided by historical analysis, inspection and monitoring. For instance, the simulation of historical events can be considered for model calibration. Moreover, the capacity of the model to numerically reproduce the existing damage constitutes a very useful calibration tool. A discussion of possible calibration approaches is presented in section 3.7.

1.7 Transparency and open doors

Implementation of remedial measures must consider social responsibility, public accountability and valorization of the discipline of conservation. In that respect, related initiatives may be considered when possible, such as: (a) having independent experts giving feedback on methodology, decisions and implementation; (b) having open worksites to observe the workers live, climb scaffolding during guided tours, observe the progress of work or diaries / video reports published regularly in a dedicated website; (c) providing technical visits with demonstration of activities and the presence of the designers and supervisors of construction works to students and selected professionals. Ungrounded limitation to the general public, students and experts constitutes an unacceptable practice.

2 ANAMNESIS: KNOWLEDGE ACQUISITION

2.1 Aims of anamnesis and proposed approach

The anamnesis phase includes all the necessary data acquisition campaigns, surveys and investigations (archives, laboratory, field and other) necessary for the subsequent phases of the study.

Knowledge of the structure requires information on its conception, on its construction techniques and materials, on the processes of decay and damage, on its evolution across the different historical periods and the changes that have been made and, finally, on its present state.

Such an investigation requires an interdisciplinary approach that goes beyond simple technical considerations. Historical research may explain aspects of structural behaviour while structural behaviour may answer historical questions. Therefore, it is important that the investigating team incorporates a range of skills appropriate to the characteristics of the building. Furthermore, the team has to be coordinated by someone with adequate experience.

Anamnesis should be based, whenever possible, on the combination and integration of the activities mentioned in section 1.4, namely historical research, inspection, monitoring and structural analysis, discussed below.

The impact of climate change on heritage structures is undeniable, necessitating its critical consideration in all conservation studies and actions. From degrading materials and structures to modifying environmental threats, climate change acts as a potent force itself. Furthermore, it influences on how historical evidence, inspection data, and monitoring records are to be interpreted. Given its pervasive influence, holistically integrating climate change into the design, application, and interpretation of conservation studies and methods is crucial.

2.2 Historical research and documentation

Historical research can provide information on the conception and the significance of the building, the original features of the structure and later historical facts or events having had a significant impact on it. The following aspects should be investigated as part of the historical research:

- A description and understanding of the structure's historical and cultural significance.
- The original materials, procedures, construction techniques and skills used in its construction.
- Subsequent changes in both the structure and its setting.
- Historical natural actions (such as earthquakes) and the damage or collapses caused.
- Any events of anthropogenic origin (such as conflicts) that may have caused damage, failures, reconstructions, additions or changes.
- Conservation works and structural interventions, structural modifications or changes of use.
- Relevant data sources, standards and codes used during the construction period. Compliance with historical rules of art and codes can be considered for a preliminary appraisal of the adequacy of the structure's design, but further assessment is necessary.

This research should cover, as far as possible, the entire past life of the structure.

Using historical documents or archaeological evidence for a better understanding of a heritage structure is not always straightforward. Several sources (such as ancient manuscripts and records) must be investigated and interpreted by specialized historians. Effective cooperation and communication between archaeologists or historians and structural engineers are needed in order to identify, collect and accurately interpret the relevant information.

Sources and documents used for this purpose must be assessed regarding their reliability as a means for the reconstruction of the structure's history and, specifically, its construction history. A careful interpretation of historical sources is essential to obtain reliable information about the structural history of a building. It should be recalled that historical documents were usually prepared for purposes other than structural engineering, and may therefore include information which is incorrect and/or may omit or misrepresent key facts or events structurally significant. Assumptions made in the interpretation of historical material should be made clear.

2.3 Inspections, surveys and investigations

2.3.1 Scope

Inspection involves all the necessary activities to characterize the current properties and condition of the structure. Among the aspects to be investigated and documented are:

- A detailed and accurate survey of the structure's geometry, including its deformed configuration, comprising all load-bearing and non-load-bearing elements, their connections and their construction features. Drawings in various appropriate scales (depending on the size of the structure) and 3D digital representations may be necessary.
- A survey of the site, soil conditions, groundwater levels and environment.
- Identification of any ongoing environmental and climate change effects.
- A detailed survey of decay and damage (including alterations such as material disintegration, efflorescence, cracks, dislocations, deformation and other).
- Characterization of deterioration processes.
- Presence of discontinuities within the structure.
- Presence of structural interaction (contacts and connections) with neighbouring buildings.
- Identification of the material types (for instance, stone and mortar types or wood species). Identification of original materials and repair ones along with their chronologies, when possible.
- Determination of the material properties (chemical, physical and mechanical).
- Characterization of the internal morphology of structural members, including the identification of multiple leaves in walls, fillings over vaults and other hidden construction features.
- Recognition of past structural interventions and identification of the historical damage (cracks, collapses…) and other problems (changes of use or functional modifications) that motivated them.
- Identification of decorative elements supported on the structure, including their connections to it.
- Historic work marks, symbols and other pieces of evidence that reveal construction details or chronology.

An accurate 3D survey may be of large interest for the following purposes:

- To study deformations and cracks in their complexity (quantitatively and qualitatively), providing information needed to identify potential collapse mechanisms,
- To provide the information needed for the construction of detailed structural models.
- To contribute to the process of simplification inherent to any modelling activity.
- To serve as a basis for the elaboration of detailed intervention drawings.

The type of technologies utilized and the extent of the operations carried out should be decided by the multidisciplinary team based on a cost-benefit optimization approach. The optimization approach should be oriented to obtain a convenient and useful amount of information at a rational cost within the budgetary constraints. Obtaining a sufficient amount of information may allow, in many cases, a more accurate diagnosis and therefore a more circumscribed intervention.

The inspection works can be divided into two different stages, corresponding to (1) the survey of the structure by direct observation and measurements, and (2) field research and laboratory testing.

2.3.2 Initial inspection by direct observation. Elaboration of an investigation program

The first inspection stage consists in direct visual observation. This stage may also include measurements by portable and simple-to-use equipment (such as devices to measure surface humidity or crack widths).

Direct observation of the structure is an essential phase of the study and should be carried out by a qualified team. The main objectives include the identification of the construction and structural features of the building, the identification of microclimate or external environmental effects and the identification and mapping of damage. Record drawings should map different materials, noting any decay and any structural irregularities and damage, and pay particular attention to material disintegration, dislocation, disconnections, crack patterns and crushing phenomena.

Direct inspection must also include an evaluation of the quality of the materials, the appropriateness of the workmanship and construction techniques, and the soundness of the original structural concept. It should also include an evaluation of the maintenance conditions (whether appropriate or inexistent) and the soil and drainage conditions.

The identification and mapping of damage may allow the formulation of preliminary hypotheses on the damage processes, possible developing collapse mechanisms and possible causes (environmental, mechanical, anthropogenic) contributing to the structural alterations. A preliminary understanding may be obtained on whether the deterioration phenomena have stabilized or are yet active. These hypotheses should be later verified by means of further research activities such as in-situ or laboratory tests and monitoring.

The preliminary inspection of the building will also allow the identification of the appropriate locations for geotechnical surveys, the execution of Non-Destructive Tests (NDTs), Minor Destructive Tests (MDTs) and the extraction of samples (using MDTs or Destructive tests) to be tested in laboratory, as needed.

The information obtained within this first phase should provide an initial understanding of the structure, its damage and the physical phenomena in need of further research. This understanding will provide the basis to:

- Decide whether there is excessive immediate risk and therefore urgent measures should be undertaken, and;
- Prepare a comprehensive (but justified and rational) program for in-situ and laboratory investigations.

Direct visual inspections, as already mentioned, will normally require a previous detailed geometrical survey of the building. This survey will be needed as a support for the damage mapping and preliminary interpretation to be carried out within this stage. In case geometrical survey is not yet available, all observations may be noted on sketches and then reworked on the detailed survey drawings and, if needed, 3D representation models.

2.3.3 Decisions on urgent actions

As part of the direct observation stage, decisions should be taken on whether there is excessive immediate risk and therefore there is the need for urgent stabilization measures, as stated above. The critical deficiencies should be assessed immediately and actions taken, if necessary. Stabilization operations should be oriented to reduce the risk with respect to public safety, avoid collapse and limit fast damage progress. Moreover, accessibility to the various parts of the structure has to be ensured, thus enabling the application of urgent measures, thorough inspection by the multidisciplinary team and later interventions if needed.

In the event of major destructive events such as earthquake strong motion and other damaging natural hazards, emergency measures based on preliminary assessments may contribute to prevent indiscriminate demolition and other inadequate actions.

2.3.4 In-situ and laboratory testing

The second inspection stage, carried out after direct visual inspection, and urgent stabilization measures, if needed, involves a detailed characterization of the materials and structure including any deterioration processes. The research carried at this stage is aimed at identifying (among other possible aspects):

- The mechanical, physical and chemical properties of the materials.
- The decay processes affecting the materials.
- The stresses and deformation in the structural members.
- The internal morphology of structural members (e.g. the presence and nature of interior rubble fillings in pillars or multiple leaves in walls).
- The presence of any discontinuities within the structure.
- The connections and the construction details.
- The morphology of foundation and soil.
- The full geotechnical characterization of the foundation soil.
- Hidden damage behind plasters, decorative elements, etc.
- The dynamic properties of the structure

This characterization requires the performance of a variety of tests (chemical, physical, mechanical, geophysical) done in-situ or in laboratory. The plan of tests should be based on the main phenomena affecting the structure, as the research effort should focus on their understanding.

As a rule, the schedule of the tests should be divided into stages, starting with the acquisition of basic data. A more detailed examination may follow with tests based upon an assessment of the implications of the initial data. However, testing should not be undertaken until its need has been established by the multidisciplinary team.

The level of intrusion of tests should always be borne in mind in relation to the disruption of the original fabric. Tests can be classified as Non-Destructive Tests (NDTs), Minor-Destructive Tests (MDTs) and Destructive Tests (DTs):

- NDTs are tests whose execution does not cause any damage or alteration on the structure and its materials. NDTs are normally based on the emission and measurement of different types of waves (electromagnetic, elastic) across the structure.

- MDTs are tests that cause very limited damage, and this damage can be easily repaired by conventional procedures. MDTs consist normally of tests that involve some type of limited drilling or surface deterioration (such as flat-jack tests or various penetrometer tests, endoscopy and small diameter core taking).

- DTs tests cause loss of material. They may involve insertions, holes and cores of large diameter or the extraction of relatively large samples. Normally, they should only cause repairable damage (and the damage should be repaired as soon as possible).

DTs should be used in a strictly limited and controlled way. They should only be performed when the needed information is not obtainable by other means or when they are indispensable to calibrate the NDTs. The potential gain in information should outweigh the loss of heritage values. In other words, the losses resulting from the tests should be significantly smaller than those that would be induced by the more severe interventions that might be necessary due to a poorer understanding of the structure. They should be preferably executed in inconspicuous areas, without significantly affecting the heritage values and without weakening or compromising the structural performance.

For the same reasons, samples taken for material testing should be kept to a minimum and generally restricted to those parts of the structure that have least heritage value.

The tests should always be carried out by skilled personnel able to gauge correctly their reliability. The evaluation of test data and results should be very carefully assessed. If possible, different methods should be used and the results compared.

Building groups (such as historical centres) may present needs and opportunities different to those of individual monuments. Generally, carrying destructive tests is more permissible (within reasonable limits) in groups of buildings belonging to historic centres. In some cases, sample extraction or destructive tests can be carried out in partially collapsed buildings, or in buildings in state of abandonment requiring significant conservation works.

2.4 Monitoring

2.4.1 Static monitoring

Static monitoring consists in the recording of structural parameters (such as displacements, rotations, crack openings, stresses, strains, etc.) over a period of time. Static monitoring by means of appropriate devices may provide quantitative information on the evolution of the response of the structure along the monitored period. In static monitoring, the monitored parameters are assumed to vary slowly. Therefore, the focus is in measuring slow trends along a sufficiently long period of time.

One of the main applications of monitoring lies in the identification of active decay or damage phenomena causing progressive alteration. Active deterioration phenomena may be identified through the detection and measurement of progressive and accumulative trends in the structural response (such as an irreversible increase in deformation or crack opening). However, characterizing damage is a challenging task due to the slowness of the processes involved and the fact that their influence may be far smaller than the variations caused by cyclic environmental actions, such as thermal changes.

The information recorded through monitoring involves normally a complex output including (1) reversible cyclic components, caused by climatic environmental changes (mainly due to daily and seasonal temperature or moisture content changes), (2) possible circumscribed increments linked to episodic events like earthquakes and (3) irreversible, monotonically increasing components caused by active deterioration processes. Extracting and quantifying the latter may be possible through appropriate mathematical post-processing procedures. In any case, identifying and quantifying the irreversible components requires a detailed characterization of the cyclic environmental effects. For that purpose, monitoring has to satisfy two conditions:

(1) In addition to the structural parameters (crack openings, movements, stresses…), it is essential to monitor also the main parameters associated with the environmental actions (temperature, humidity, wind speed and direction, variation of groundwater level, …).
(2) The monitoring period has to be sufficiently long to encompass a number of entire seasonal cycles. Since a first entire year may be needed to calibrate the initial relationship between environmental and structural variables, identifying possible evolution trends may require a period of several years. Due to the significant cost of long-term monitoring, the extent of monitoring should be carefully assessed and limited to the acquisition of the data strictly necessary to reveal the progression of the phenomena investigated.

In some cases, placing graduated tell-tales and taking systematic measurements over a period of time may be used as a simpler and inexpensive way to monitor cracks, with the necessary cautions and interpretative requirements. It must be noted, however, that the correct interpretation of these markers may require sufficiently frequent observations combined also with a detailed characterization of thermal and humidity variations.

Monitoring requires the identification of the critical variables (movements, crack widths…) and the critical zones of the structure, and adequate devices to check them in the long term. Monitoring may be oriented to either survey the evolution of a non-intervened structure or to assess the effectiveness of an intervention carried out. The number of points or variables controlled and the frequency of their measurement may be reduced as the understanding of the structural response improves.

2.4.2 Dynamic monitoring

Dynamic monitoring may be used to record the response of the structure during the occurrence of seismic events, strong wind episodes, train passage or other episodic (normally dynamic) actions, or alternatively using ambient vibration to identify slowly progressive damage. For that purpose, the information is sampled at high speed during the duration of the monitored event or at regular intervals for ambient vibrations. Dynamic monitoring can be used to characterise the dynamic properties of the structure, such as periods (or frequencies), vibration modes (modal shapes) and damping. It can also contribute with useful information for the calibration of structural models. The variables normally monitored are velocities or accelerations at critical points of the structure.

Dynamic monitoring can be performed according to different strategies:

- Periodical repetition of dynamic inspection: A dynamic inspection experiment is repeated periodically (i.e., every year) in order to investigate the variation of the main dynamic properties of the structure.

- Threshold monitoring: A monitoring system is automatically activated when certain signal (the accelerations or velocities) surpasses a given threshold due to an occurring seismic tremor, wind episode or other.

- Continuous monitoring: The dynamic recording performed continuously during a period of time at a high sample rate allowing the investigation of the evolution of the dynamic performance over time. This is usually carried out at fixed intervals to limit the amount of data generated.

2.5 Application of structural analysis to anamnesis

As mentioned in section 1.6, structural analysis can provide useful information during the anamnesis phase. A preliminary structural analysis can be used to identify the main structural features and vulnerabilities, thus contributing to the design of a more accurate and efficient investigation program. For this purpose, the structure can be analysed under meaningful actions, including gravity loads, wind and earthquake, soil settlements and thermal effects, among other. This stage may be undertaken with a simplified model not yet providing all the detail and accuracy required in subsequent phases.

3 DIAGNOSIS AND ASSESSMENT OF THE STRUCTURAL PERFORMANCE

3.1 Aim of diagnosis and assessment of the structural performance

The aim of diagnosis is to identify the cause or the concomitant causes of damage on the basis of the data acquired in the anamnesis phase. In turn, the assessment of the structural performance is aimed to the evaluation of the structure's response in its current condition and the identification of possible intervention needs.

The assessment of the structural performance of architectural heritage involves a multi-dimensional problem in which the conventional serviceability and ultimate limit states are considered along with the safeguarding of the possible valuable artistic contents and the preservation of the structure's authenticity and heritage values. In specific, the adequate performance of the structure must be evaluated considering three different but intimately related targets:

(1) The safety of people.
(2) The safeguard of valuable immovable cultural and artistic contents.
(3) The integrity of the structure itself as cultural heritage object with the least possible alterations.

In certain instances, such as in the presence of valuable paintings, frescoes or mosaics fixed to walls or vaults, or other immovable cultural contents, condition (2) requires some limitation on the deformation and damage that the structure may experience. In order to limit damage on valuable immovable cultural contents, specific serviceability limit states oriented to limit deformation and cracking may be considered.

Objectives (1) to (3) will lead to the definition of the acceptable damage levels and the structural requirements. Structural performance assessment, carried out according to the procedure described below (section 3.2), can provide a verdict on the structure's sufficiency and the possible need for a strengthening intervention.

As mentioned in section 1.3, the definition proposed for minimum intervention enables a formal analysis by formulating an objective function and constraints. The objective function minimizes the intervention's impact on heritage values (target 3) while the constraints ensure the safety of people (target 1) and the safeguard of immovable cultural contents (target 2). The engineering approach that may lead to the identification of a minimum intervention for a given structural performance is described in section 4.4.

It must be noted that, in some cases, the protection of the structure's cultural value may require the acceptance of safety levels lower than those implicit in building design codes for modern or existing buildings. No absolute value is given to safety, allowing a compromise with conservation needs which is not different conceptually than that required for existing non-heritage structures in which safety levels are defined as a compromise with construction costs and expected losses. The need for a reconsidered safety level may emerge whenever the approach proposed for the design of optimal interventions does not permit the identification of a satisfactory solution with sufficiently limited impact on the structure's heritage values. In these cases, parallel measures such as restricted use or provision of alternate escape routes should be adopted to limit the consequences of a failure on people. In addition, it may be possible to place valuable movable cultural contents in a nearby building or building part, providing appropriate safeguard.

3.2 Proposed approach for diagnosis and structural assessment

Diagnosis is often a difficult phase since the data available usually refer to the effects, while it is the cause or, as it is more often the case, the several concomitant causes that have to be identified. This is why experience and engineering judgement are essential components in the diagnostic process. A correct diagnosis is indispensable for a proper assessment of the structural performance and a rational decision on the treatment measures to be adopted.

The assessment of the structural performance is also a difficult task because methods of structural analysis intended for new construction may be neither accurate nor reliable for historic structures and may result in inappropriate decisions. This is due to such factors as the difficulty in fully understanding the complexity of an ancient building or monument, uncertainties regarding material characteristics, unknown phenomena (for example soil settlements), and imperfect knowledge of alterations and repairs carried out in the past. Therefore, the assessment of the structural performance should not only lie on a quantitative approach based on mathematical models; as with diagnosis, qualitative approaches based on historical research and observation should be also considered.

Thus, the diagnosis and assessment of the structural performance should be based on the broad approach described in section 1.4 and should therefore combine different activities contributing with both qualitative and quantitative evidence. Similarly to anamnesis, four complementary approaches can be considered:

- Historical approach, based on the investigation of the past performance of the structure.
- Comparative approach, based on the comparison of the structure being analysed with a number of similar constructions whose behaviour is already understood.

- Experimental approach, consisting in the execution of on-site experiments aimed to measure the load capacity of structural members.
- Analytical approach, based on the use of structural analysis to predict the performance of the structure. Within the diagnosis stage, structural analysis is utilized to investigate the effects of past actions. In the framework of the assessment of the structural performance, structural analysis is used to predict the response under future actions.

3.3 Historical approach

History can be understood as a natural experiment developed in true space and time scales. This experiment accounts for the effect of real actions occurring in historical periods which cannot be reproduced in laboratory or be monitored in the real building. Historical research can provide important clues for the understanding of the present condition or the response of the building when subjected to major actions.

Prior to the design of the intervention, it is important to decode the damage history and the possible transformations that have occurred in a historical structure. The study of the history of the structure helps to develop an understanding of whether the structural system has performed satisfactorily in the past.

However, the historical approach, as any individual approach, is not enough to obtain reliable conclusions. For instance, the capacity of a building to resist its gravity loading or an earthquake can be compromised in the future by the accumulation of damage or by structural alterations. Moreover, earthquakes may differ very much in signal orientation and duration, magnitude and seismic frequency contents; each seismic event constitutes a genuinely distinct action. The insights gained through historical investigation must be set against the evidence provided by the other approaches.

3.4 Comparative approach

This approach is based on the comparison of the present condition of the structure with that of other similar structures whose behaviour is already understood. Experience gained from analysing and comparing the behaviour of different structures can enhance the possibility of extrapolations and provide a basis for structural verification.

The possibility of extrapolating must be judged by the analyst. In any case, sufficient similarity must exist in terms of geometry and dimensions, materials, structural organization and actions.

Having observed the behaviour of different structural types in varying stages of damage and decay caused by different actions (earthquakes, soil settlement, floods, etc.), and having acquired experience of their expected condition and damage, it is possible to extrapolate this knowledge to predict the behaviour of the structure under examination. The reliability of the evaluation will depend on the number of structures observed and, therefore, on the experience and skills of the experts involved. Reliability can be increased by an appropriate programme of investigation and monitoring of progressive phenomena.

This approach has yielded valuable results in the systematic study of the performance and collapsing mechanisms of buildings affected by earthquakes. Simple but useful evaluation methods, based on the study of typical collapsing mechanisms, have been created after a careful study of the effects of earthquakes in a large number of buildings. Comparison and extrapolation, supported on wide collective experience, has become a common way of evaluating the condition and weaknesses of churches or vernacular buildings built with similar construction techniques. The adequacy of this approach is highlighted by the evidence that similar structures tend to experience recurrent damage and collapse modes, as observed after recent earthquakes.

3.5 Experimental approach

A direct evaluation of the bearing capacity of structures can be obtained by on-site experiments involving the application of real loads. The aim of these experiments is the direct measurement of the capacity to resist a real action. Direct experiments involving significant loads can hardly be carried out on the entire structure; more likely, the experimental analysis will be utilized to assess the load capacity of individual members such as floor slabs, vaults or stairs.

Another possibility is offered by laboratory experiments. Laboratory tests can be carried out on specimens or structural components taken from the real structure or on purpose built in laboratory as full scale or scaled mock-ups of their real counterparts. The applicability of the first strategy is limited because of its destructiveness; moreover, taking unaltered specimens from the real structure to the laboratory may be difficult. The second strategy may show limited realism due to the difficulty in reproducing the real materials and the construction technologies. That is why such experiments have to be very carefully designed to enhance the reliability of the results while respecting the characteristics of the structure.

3.6 Application of structural analysis to diagnosis and structural assessment

During the diagnosis and the assessment of the structural performance, structural analysis can be utilized to investigate the performance of the structure under a variety of past and future actions. The simulation of meaningful past actions can provide insight on the causes of damage and their impact on the present condition of the structure. These actions may include gravity loads, past earthquakes, wind, soil settlements, chemical, physical or biological attack, anthropogenic alterations, thermal cycles, floods and other. Structural analysis can be utilized to characterize the possible role of such actions in causing existing damage and possible partial collapses.

In turn, the prediction of the structural response for the foreseen future actions (new loads, wind, earthquake and other) can contribute to characterize the performance of the structure in its present condition and the need for possible repair and strengthening interventions. Compared to the comparative approach, which is an inductive procedure, this approach (the analytical approach) constitutes a deductive process. The information on the structure, morphology, resistances, damage and actions is invested in constructing a structural model which is then used to predict the structure's performance under the future actions. It is advised to adequately simulate in the model existing damage in order to capture its influence on the response and allow conclusions on the need and extent of repair and strengthening.

As discussed in section 1.6, models must be always calibrated using the available evidence on the condition and behaviour of the structure. Some possible calibration strategies are mentioned in the following section.

However, a full validation is not actually possible and significant uncertainty may remain in spite of the calibration effort. Engineering judgment is necessary to evaluate the feasibility and reliability of the predictions and the correct use of the entire procedure leading to model construction, calibration and prognosis. Historical analysis and comparative analysis may be of large assistance in this purpose.

Structural analysis may be a difficult task in the case of groups of buildings because of their interaction and the fact the boundary conditions may be mostly unknown. In these cases, other approaches can be successfully applied. For instance, qualitative analysis may be very suitable for the study of constructions in historic centres. Nevertheless, analysing some carefully selected substructure using quantitative methods remains necessary.

3.7 Model calibration

Calibration and validation of models is done by comparison between numerical predictions and observations yielded by historical research, inspection, monitoring or experimental analysis. An unsatisfactory comparison should lead to the reconsideration and improvement of the model until sufficient agreement is obtained (the so-called "model updating" process).

The following possibilities, among other, can be considered for this purpose:

- Visual inspection, allowing comparison between damage numerically predicted under past actions and actually existing damage.
- Characterization of structural past performance through detailed historical research, and comparison with the corresponding model predictions. In particular, study of past-performance in the case of historical earthquakes.
- Measurement and comparison of stresses at critical points under existing loads. Stresses can be experimentally measured by simple flat-jack tests in masonry or hole-drilling tests in stone.
- Dynamic inspection (identification), permitting characterization of the dynamic properties (frequencies and modal shapes), and comparison with the output of modal analysis. This technique is conventionally known as "modal matching".
- Static monitoring involving the characterization of actions (temperature, humidity, wind, microtremors) and response (cracks, displacements, rotations), and comparison with a simulation of the response of the numerical model subjected to the same actions.

Sensitivity analysis should be considered after model calibration, in order to evaluate the influence of the most relevant or least certain hypotheses (e.g., material data, connections) in the results.

3.8 Synthesis of approaches

The judgements on diagnosis, structural performance and intervention needs must be based on the synthesis of the evidence provided by the aforementioned approaches (sections 3.3 to 3.6). Their consistent integration may allow a prognosis on the structural response before and after the implementation of possible remedial actions.

As many approaches as possible should be activated among the four approaches discussed. Using more than one approach will permit a critical analysis of the evidence made available in terms of consistency, completeness and corroboration.

(1) The consistency of the information provided by different approaches should be carefully investigated with the aim of identifying possible contradictions. The presence of contradictions should lead to a critical reconsideration of the results obtained and to perform improved investigations until such contradictions are explained or solved. A "plausibility check", consisting of investigating the possible presence of contradictory outcomes among the different approaches should be systematically carried out. In specific, application of the "plausibility check" to analytical or numerical models is of large importance as a way to verify the compatibility of their results with the evidence provided by historical research, inspection and monitoring.

(2) Completeness refers to the need to obtain the necessary reliable and sufficient information on the relevant variables of the problem (including the characterization of the geometry, materials and actions, among other aspects).

(3) Corroboration will occur when the information provided by different approaches supports some evidence or conclusions in a redundant way. As a general rule, and given the fact that all approaches show some practical limitations, redundancy and corroboration should be sought during the analysis and the synthesis of the approaches.

When the evidence obtained through the different approaches does not satisfy the above requirements in an acceptable way (and, for instance, it shows unacceptable contradictions), additional effort is needed in order to improve the methods applied, enrich the available information and reconsider the adopted criteria.

The process leading to the verdict on the structural performance, based on the synthesis of the approaches, is not formalized in practice and relies on engineering judgment. In any case, the process and corresponding decisions need to be documented and justified throughout their steps.

4 THERAPY

4.1 Intervention criteria

The design of a minimum intervention, as defined in section 1.3, can be facilitated by considering the following criteria:

Compatibility with the original materials and techniques. Compatibility is a key concept in structural conservation as well as other fields of conservation sciences. In structural conservation, compatibility should be considered at different scales from the material to the structural elements and up to the structural system. At material level, the physico-chemical compatibility of the materials used in interventions with respect to the original materials is a fundamental requirement to minimize the risks of unpredictable side effects. Physico-chemical compatibility relates to the effect of new reactive material when applied in adjacency to or to a historic substratum. The parameters that will determine such compatibility are the chemical composition, pH level, porosity, bulk and dry density, capillarity, texture, salt content, rate of aging, colour change, thermal expansion coefficient, etc.

At material and element level the mechanical compatibility is also an essential criterion in defining the acceptability of an intervention. This relates to the stiffness and strength not just of the material but also of the connected structural elements. The mechanical behaviour of such elements in the medium to long term also needs to be considered, in particular the propensity to shrink or creep in presence of changes in moisture or continued applied loading conditions, as well as any state of deformation caused by differential thermal behaviour, altering the state of stress in the structure. The latter is best controlled at the structural system level.

Durability. Heritage structures are intended to last for many generations and, therefore, should be repaired or strengthened with materials, techniques and devices that provide satisfactory durability. Insufficient durability of the new material may induce its expansion, cracking or debonding which may in turn damage the original one. Iron and steel corrosion, for instance, has been a source of massive damage in restored heritage structures. Moreover, the safety of the structure can be compromised by the loss of the efficiency of the strengthening.

Non-invasiveness. Non-invasive repair or strengthening techniques should be preferred to more invasive alternatives.

Re-treatability. Care has to be taken to ensure that future generations will be able to intervene again to remediate possible future damage. A present intervention should not compromise future interventions.

Removability. Whenever possible, the measures adopted should be such that they may be removed and replaced with more suitable measures if required. As a general principle, no intervention should compromise its future replacement. The replacement may be motivated by insufficient effectivity or by new technological developments.

Enhanced compatibility, durability and re-treatability should be ensured in the case of non-removable interventions.

Removability implies that the dismantlement of the intervention will only generate limited and repairable damage on the original construction. Interventions whose dismantlement will cause excessive damage do not satisfy this criterion.

A distinction can be made between the concept of removability, which accepts limited damage, and that of full reversibility, whose objective is restoring a fully intact previous state. This text adopts removability because of its more realistic and achievable nature.

Feasibility. The proposed solution has to be checked regarding its feasibility considering the location where the structure is built, the availability of materials, the necessary equipment, etc.

Controllability. It must be possible to control the intervention during its execution. Measures that are impossible to be controlled should not be allowed. Whenever possible, monitoring should be used to control the adequacy of the performance of the structure during the execution of the intervention. It is also desirable to use monitoring to control the performance of the repaired or strengthened structure during a certain period of time following the intervention, as a way to assess its effectiveness.

Sustainability. Sustainable materials and technologies characterized by low environmental impact during their life cycle (manufacturing, transportation, placement or removal) should be preferred. It is noted that the manufacture of traditional materials, such as timber, lime mortar and clay brick, requires comparatively low energy consumption compared to other materials such as concrete and steel. In turn, conservation or rehabilitation are intrinsically sustainable activities since the reuse of existing buildings avoids demolition and therefore massive production of construction waste. It is also noted that some traditional techniques (e.g., some wood chemical preservatives or oil-based paints) are facing restrictions due to health, safety, and environmental impact.

4.2 Application of intervention criteria in practice

Applying all the mentioned criteria in a simultaneous and strict way may be difficult in practice. The criteria should not be understood as absolute principles, but as convenient guidelines or inspirational principles assisting in the design of solutions approaching the concept of minimum necessary intervention.

Depending on the nature of the problem (type of structure, type and severity of damage, strengthening needs) some criteria may be prioritized. In any case, the prioritization should lead to efficient solutions ascertaining satisfactory conservation.

For instance, compatibility with the original material and durability may be prioritized over removability or non-invasiveness. The use of durable repair materials (such as lime mortar, stone, clay brick) may be considered for in-depth and non-removable operations provided that the requirements on durability and all forms of compatibility are granted. For instance, repointing or injection with adequate mortars or grouts to repair poor or defective masonries can normally be regarded as an acceptable and even optimal solution complying with the concept of minimum intervention.

In other cases, non-invasiveness and removability may be prioritized over durability. For instance, an external and removable strengthening system made of a non-so-durable material (as steel) may be acceptable if it can be subjected to proper maintenance and may actually be removed if necessary. Even in this case, it may be advisable to use a comparatively more durable material (stainless steel rather than carbon steel).

The strategy of the intervention may belong to one of the following general categories or a combination of them: (1) Reinstating the capacity of part or all of the structural elements to selectively increase strength, stiffness, ductility or a combination of these; (2) Insertion of new structural elements, compatible with existing ones, to eliminate local vulnerability of certain parts of the construction and to improve the overall capacity; (3) Introduction of passive protection by means of dissipative elements and/or base isolation to reduce demand; (4) Mass reduction to reduce demand; (5) Limiting or changing the use of the building to reduce exposure.

Any proposed intervention must consider the temporary situation during the execution of the works when there may be a higher level of risk. Such situations appear frequently in structures that have already suffered considerable damage, as in post-earthquake works.

The proposals should distinguish between works that are urgent, those that are essential for both the immediate and long-term stability, and those that are desirable as a means by which the reliability levels are improved over the minimum required.

4.3 Repairability. Pre- and post-natural hazards structural maintainability

In seismic regions, historical buildings are exposed to the impact of repeated earthquakes across their life. Thus, moderate or even severe damage may occur repeatedly depending on the quality of construction and soil conditions. In this context, the post-earthquake structural interventions aimed to repair damaged structures can be regarded as a phase of a unique maintenance project across a time horizon involving their past and future life. Historical structures have to coexist with seismic or other natural disasters and should continue to be able to withstand them by appropriate pre- or post-earthquake structural interventions allowing the preservation, to the extent possible, of their original construction characteristics. In this sense, a global understanding of pre- or post-earthquake operations is provided by the concept of structural maintainability, which can be defined as a continuous maintenance program involving minimal repair or minimal strengthening operations to be undertaken after each earthquake. Such maintenance interventions, which may involve structural operations, should be designed so that they do not hinder future ones. The same concept could be applied to any type of environmental action that might endanger the survival of the structure.

The concept of structural maintainability is implicit in the traditional methods for post-earthquake repair since all historical structures in seismic zones have experienced repeated repair or strengthening operations over their history. The structural maintainability approach highlights the need for minimizing the intervention from a mechanical point of view, thus avoiding strong alterations of the structural response, a condition that ensures more reliable structural responses to future earthquakes. The structural maintainability concept may offer a satisfactory way to unite pre- and post-earthquake repair and conservation needs, and may provide a practical approach for an adequate interpretation and application of the principle of minimum intervention.

4.4 Proposed engineering approach for the design of the intervention

The use of the criteria defined in sections 4.1 and 4.2 may provide satisfactory solutions, close to the concept of minimum intervention. However, identifying a true minimum intervention (as defined in section 1.3) may require some additional considerations.

In practice, the identification of the minimum intervention may result from the engineering approach set out here and in Figure 2. First, a number of alternative solutions based on different strategies or technologies can be envisaged. As far as possible, these solutions should comply with the criteria defined in section 4.1. The structural performance should be assessed for all the solutions and only those that verify the adopted structural requirements (as described in section 3.1) should be considered further on.

The impact of all envisaged alternative solutions, in terms of loss of authenticity and heritage values, should then be evaluated. The optimal solution, among all solutions considered, will be the one that, while satisfying the structural requirements, causes the minimum loss on the heritage values.

For obvious reasons, the success of this approach will depend strongly on the designer's ability to conceive a variety of alternative technical solutions.

The evaluation of the impact of the proposed interventions on the heritage values is a task to be performed by the multidisciplinary team. The evaluation should be based (although not exclusively) on the compliance of the interventions with the criteria discussed in section 4.1.

If all the envisaged alternative solutions cause excessive impact to the heritage values, the targeted reliability levels may be reconsidered and reduced according to the criteria indicated in section 3.1.

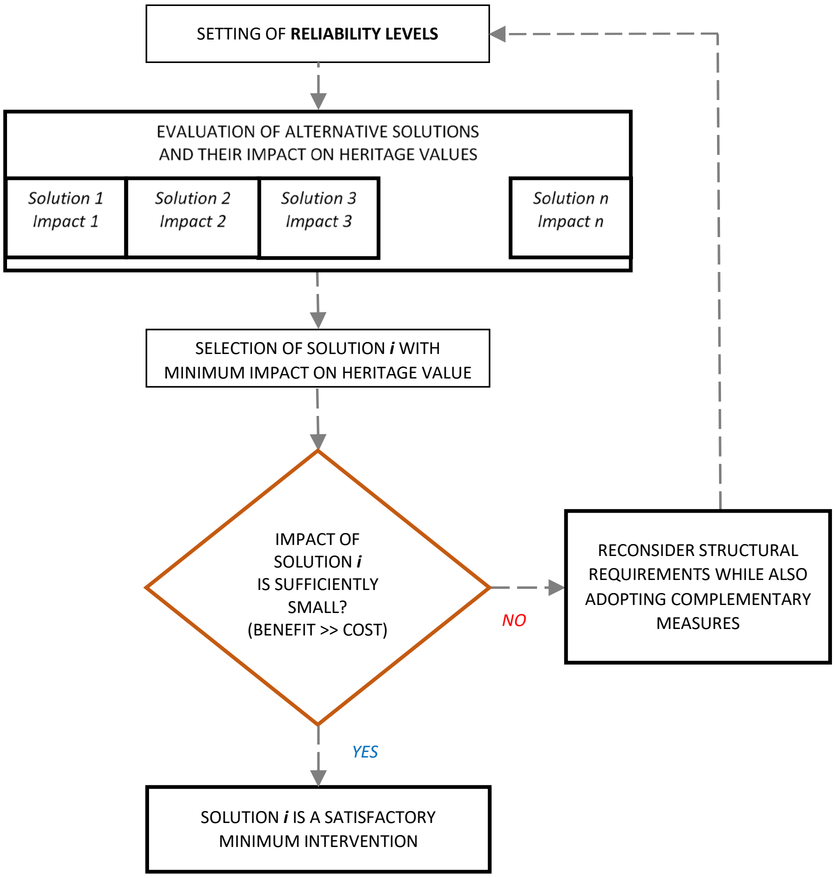

Figure 2. Flowchart describing the proposed engineering approach for the selection of minimum interventions.

4.5 Use of structural analysis within the therapy phase

As mentioned in section 1.6, structural analysis has a critical role within the therapy phase. The application of the engineering approach presented in the previous section requires carrying out detailed studies on the structural performance of all envisaged alternative intervention solutions in order to select those that satisfy the structural requirements. These studies should be performed with models similar in accuracy and realism to those previously utilized for diagnosis and for the assessment of the structural performance before the intervention.

Models already developed and validated in the previous phases can be used with the necessary modifications to accurately describe the effect of the repair and strengthening operations. The interventions can be simulated by the adequate integration in the model of the strengthening measures (such as diaphragmatic floors) or by an appropriate modification of the mechanical properties assigned to the materials or structural members. In any case, the modelling approach must be based on a careful and realistic description of the effect of the intervention on the structural response.

The analysis of the structure within this phase may require a reconsideration and updating of the actions to be simulated due to possible changes in use and conditions to which the structure is subjected.

4.6 Incremental approach

A possible strategy towards minimum intervention can be found in the application of an observational method (or incremental approach): a step-by-step procedure of structural conservation is adopted which begins with a minimum level of intervention followed by the possible adoption of subsequent supplementary or corrective measures. When the complexities of the problem prevent clear and reliable solutions without extensive intervention, the incremental approach may be the best course of action. The incremental approach is strongly based on monitoring, either static or dynamic, or both. Observation and monitoring are used to assess the efficiency of each subsequent measures and to evaluate the need for further operation.

The applicability of the incremental approach to interventions oriented to improve the structural response against progressive phenomena such as soil settlements or extraordinary actions such as earthquake must be assessed carefully by the responsible team. Due to their hazardous nature, monitoring the structure's response under extraordinary actions may be difficult or even impossible within a reasonably short period of time.

5 CONTROL

The entire process discussed in the previous sections, including the anamnesis, diagnosis, structural performance assessment and therapy phases, must be subjected to quality control assessment. Control should be oriented to grant the accuracy and adequacy of the studies, decisions and operations undertaken. Control must also be extended, in the long term, across the post-intervention and maintenance phases.

Quality of interventions to preserve and restore heritage structures results from the compliance with the general criteria stated in section 1 and the applicable specific criteria stated in section 4.1. Any conservation project should begin with a section presenting the conservation principles or concepts specifically applied.

Studies and interventions in ancient structures are generally more complex than in standard construction, and require that the various professionals called upon implement appropriate methods and technologies. There is the need to ascertain that the adequate approach for investigation and conservation will be respected through the process leading to the execution of the intervention.

The success of interventions in heritage buildings is seriously compromised if such interventions are not entrusted to professionals with the necessary qualifications across the different phases of the study. Professionals making up the multidisciplinary team should possess the necessary qualifications in terms of training and experience in their areas of expertise.

Any intervention project on a heritage structure must contain all the necessary instructions on control operations during and after the intervention works. The project must also include instructions on the application of inspection works (such as the application of NDTs) and a monitoring plan to assess the efficiency of the intervention in the short and long terms. Specific instructions have to be included for the inspections to be carried out after an important earthquake or other natural hazard event. Moreover, the foreseen monitoring and intervention plans should be updated during their implementation as required by the encountered real conditions.

Furthermore, intervention projects should also include detailed maintenance plans with all the necessary specifications that may be required to preserve the structure in a satisfactory condition. It is also noted that maintenance of non-structural elements and systems (roof condition, drainage, climatic control…) may be necessary to ascertain a proper structural condition.

6 EXPLANATORY REPORT

According to the general framework described in section 4, the decisions on the proposed interventions must be the result of the collaboration between all members of the multidisciplinary team. These decisions must be communicated to the owners and decision makers (or other parties responsible for the building) in a simple and non-technical manner through a report – the explanatory report – specifically oriented to explain and justify the decisions taken in a way understandable to non-technical agents. The explanatory report is a summary and commentary on the more detailed and specialised reports produced by the multidisciplinary team and includes a synthesis of their findings. In the report, the technical content is considered together with the cultural, social and economic factors.

The purpose of the explanatory report is to explain those aspects that cannot be reduced to formal calculations. The report must explicitly present and discuss the reliability of the data, any uncertainties, the hypotheses used and the degree of caution being exercised at each stage. Qualitative judgements may play a role as important as the quantitative data obtained through the investigations carried out.

The report should include a description of the alternative intervention solutions envisaged, along with the pros and cons of each, which can involve a case-by-case considerations on their compliance with the structural requirements and their impact on the heritage values. The criteria and procedures considered in the evaluation of the alternative solutions and the selection of the optimal one should be also clearly explained. Such a detailed analysis justifies the final proposal and provides the best guarantee of the quality of the project.

The application of the incremental approach, whenever adopted, must be clearly described along with the methods or strategies proposed for its application.

Uncertainties in the data used and/or difficulties in modelling the complex nature of the structure may affect the reliability of the analysis. In such cases, the nature of the resulting uncertainties should be made clear. The degree of caution being exercised in assessing the present safety of the structure should also be made clear.

There may be two alternative courses of action: to proceed on the basis of the data available, or to delay any decision and extend the investigation of the structure to obtain more reliable information and so reduce the level of intervention necessary. The likely benefits of the second course of action should be clearly set out, but the increased risk associated with delaying action should also be explained.

The report should be open and regularly updated while the works are still being developed and particularly after each intervention phase.

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ANNEX 1

GLOSSARY

GLOSSARY OF TERMS

The Glossary is limited to the meaning of terms as they are used in the document.

Aesthetic value – Value related to aspects such as the form and decoration in the exterior and interior

Analytical approach – Approach based on the use of structural analysis to predict the performance of the structure

Anamnesis – Historical, architectural and structural data acquisition campaigns and all the investigations (laboratory, field and other) necessary to derive final conclusions on diagnosis, assessment and therapy

Architectural and structural inspection (including surveys and investigation) – Inspection for characterization of the current condition and properties of the materials and structure, including its foundation and setting.

Character-defining elements – Features that contribute to heritage values and authenticity of the structure

Comparative approach – Approach based on the comparison of the structure being analysed with a number of similar constructions whose behaviour is already understood

Compatibility with the original materials and techniques – Compatibility (namely physical, chemical and mechanical) of materials and technical devices used to stabilize, repair or strengthen a structure with the original materials and techniques

Conservation of historical structures – Assurance of structural performance and preservation of all tangible and intangible values that contribute to authenticity and cultural dimension of structures Conservation - all measures and actions aimed at safeguarding tangible cultural heritage while ensuring its accessibility to present and future generations. Conservation embraces preventive conservation, remedial conservation and restoration. All measures and actions should respect the significance and the physical properties of the cultural heritage item.

Constraints of the intervention – Structural requirements essential for ensuring people's safety and protecting valuable immovable cultural and artistic contents

Control – Quality control checks and monitoring campaigns to be implemented for verification purposes before, during and after the execution of the intervention, including also a detailed maintenance plan

Controllability of intervention – Possibility to control the intervention during and after the execution (see Control)

Direct observation – The first inspection stage including the identification of the construction and structural features of the building, the identification of microclimate or external environmental effects and the identification and mapping of damage

Destructive Tests (DTs) – Tests that cause relevant loss of material. They may involve insertions, holes and cores of large diameter or the extraction of relatively large samples. Normally, they should only cause repairable damage (and the damage should be always repaired as soon as possible)

Diagnosis and assessment of structural performance – Identification of the causes of damage and decay, characterization of structure's conservation condition, evaluation of the performance of the structure in its current state and the identification of the intervention needs

Durability of intervention – Heritage structures are intended to last for many generations and, therefore, should be repaired or strengthened with materials, techniques and devices that provide satisfactory durability

Dynamic inspection (identification) – Characterization of the dynamic properties (frequencies, modal shapes and damping)

Dynamic monitoring – Recording the response of the structure during the occurrence of seismic events, strong wind episodes, train passage or other episodic (normally dynamic) actions, or alternatively using ambient vibration to identify slowly progressive damage

Enhancing resilience against climate changes – Applying measures such as flood protection and improved stability against temperature and humidity changes

Experimental approach – Approach based on the execution of on-site experiments aimed to measure the load capacity of structural members

Explanatory report – Summary and commentary on the more detailed and specialised reports produced by the multidisciplinary team including a synthesis of all findings, oriented to explain and justify the decisions on intervention in a way understandable to non-technical agents

Feasibility of intervention – Availability of materials, necessary equipment, workmanship, etc. with respect to the location where the structure is located

Historical value – Value related to the symbolism and function of the building

Historical approach – Approach based on the investigation of the past performance of the structure

Historical research – Study of the historical features and response of the structure through the investigation of documentary sources

ICOMOS/ISCARSAH Guidelines for the analysis, conservation and structural restoration of architectural heritage – Document intended to provide criteria and assistance for the inspection, assessment and intervention on heritage structures

Incremental approach – Approach, strongly based on monitoring, beginning with a minimum level of intervention which is then followed by the possible adoption of subsequent supplementary or corrective measures

Initial inspection by direct observation – First inspection stage, consisting of direct visual observation including measurements by portable and simple-to-use equipment (such as devices to measure surface humidity or crack width)

In-situ and laboratory testing – The second inspection stage, carried out after direct visual inspection and urgent stabilization measures, if needed, involving a detailed characterization of the materials and structure including any deterioration processes

Minimum intervention – Set of structural measures of high technical quality that optimally combines compliance with structural requirements necessary for the protection of human lives with the best possible protection and enhancement of the heritage values, while also paying attention to environmental impact and cost effectiveness

Minor-Destructive Tests (MDTs) – Tests that cause very limited damage, which can be easily repaired by conventional procedures

Model calibration and validation – Calibration and validation of the model by comparison between numerical predictions and observations yielded by historical research, inspection, monitoring or experimental analysis

Monitoring – Observation of the response of the structure over a period of time

Multicriteria analysis – Analysis that combines qualitative and quantitative criteria by using a logic tree decision

Multidisciplinary team – Team of different experts (engineers, architects, archaeologists, historians, geophysicists, chemists and other), working together to reach a common decision on the optimal intervention

Non-Destructive Tests (NDTs) – Tests whose execution does not cause any damage or alteration on the structure and its materials

Non-invasiveness of intervention – Non-invasive repair or strengthening techniques used for an intervention

Objective function of the intervention – The impact of the intervention on heritage values

Optimization process – Process oriented to select the best possible solution

Plausibility check – Investigation of the possible presence of contradictory outcomes among the different approaches

Prognosis – Forecast of the likely outcome of the current situation, leading to the decision on whether it is appropriate to intervene and therefore the definition of the therapy

Reconstruction – Action or process that aims at returning, to the extent that is possible, a destroyed or severely damaged heritage place to a previously known state of integrity while preserving the authenticity of as many attributes as possible

Removability – Possibility of removal and if needed replacement of the intervention with more suitable measures, while accepting limited damage during the process

Repairability – Possibility of repetitive post-earthquake repair (or other recurrent events) as a phase of a unique maintenance project across a time horizon involving the past and future life of the structure

Re-treatability of intervention – Ensuring the possibility of future conservation interventions to remediate possible future damage

Reversibility – Restoring a fully intact previous state

Sensitivity analysis – Analysis considered after structural model calibration, in order to evaluate the influence of the most relevant or least certain hypotheses (e.g., material data, connections) in the results

Social value – Value related to the cultural memory, the continued use of the historic building, its educational potential and the economic dimension of the conservation programme

Static monitoring – Recording of slowly-changing structural parameters (such as displacements, rotations, crack openings, stresses, strains, etc.) over a period of time

Structural analysis – Characterization of the response of the structure under a variety of conditions and actions

Structural maintainability – Possibility of applying continuous maintenance program involving minimal repair or minimal strengthening operations to be undertaken after each earthquake

Structural model – Model chosen and constructed to provide a satisfactory description of all the relevant mechanical and resisting phenomena characterizing the response of the structure

Structural restoration – Type of repair carried out on a building or structure with the goal of rehabilitating its original structural integrity. This process involves addressing damage, deterioration or other issues that may have compromised the stability and functionality of the structure. Whether it' strengthening load-bearing elements, repairing foundations or enhancing overall safety, structural restoration aims to bring the building back to its intended state of strength and stability.

Sustainability of intervention – Use of sustainable materials and technologies characterized by low environmental impact during their life cycle

Technical value – Value related to the structural concepts, construction techniques and materials

Therapy – Design of alternative intervention schemes and the assessment of their efficiency, identification of the optimal solutions and detailed definition of the intervention strategies with the necessary design details and specifications of materials and techniques

Transparency and open doors – Considering social responsibility, public accountability and valorization of the discipline of conservation

Urgent stabilization measures – Stabilization operations oriented to reduce the risk with respect to public safety, avoid collapse and limit fast damage progress, while ensuring accessibility to the various parts of the structure

ANNEX 2

CHECKLIST

CHECKLIST FOR IMPLEMENTATION OF ICOMOS/ISCARSAH GUIDELINES

Project:

Project phase:

Place:

Client:

Date:

Prepared by:

This checklist is a summarised list of tasks based on the ICOMOS/ISCARSAH Guidelines for the analysis, conservation and structural restoration of architectural heritage. The checklist serves as a table overview and cannot be used without the Guidelines, which explain all tasks in the required detail.

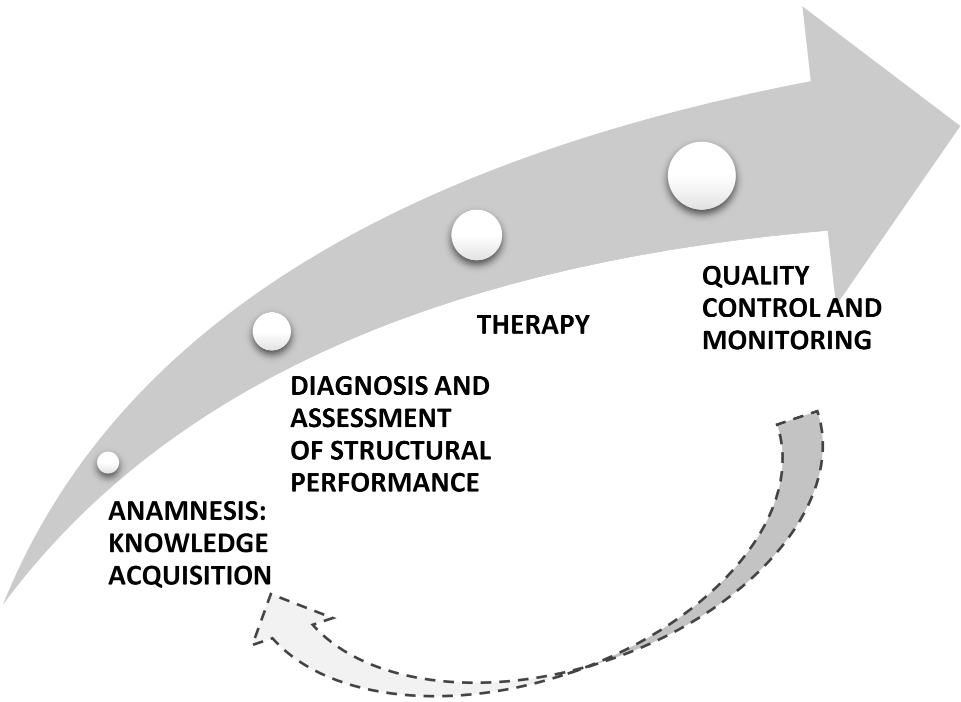
The checklist is intended to be used at different phases of the project (i.e., the original design development, the execution of the works, and the subsequent control and maintenance).

Column 1 in the checklist sorts the tasks listed in column 2, with a reference to the Guideline's sections, given in column 3 of the Checklist.

Column 4 of the checklist is foreseen to explain the intention of performing the tasks:

- yes = planned to be performed or actually performed,
- no = not planned to be performed or not performed,
- tbc = performing the task to be confirmed (status unknown),
- n/a = not applicable.

Column 5 of the checklist is foreseen for additional comments to be marked by numbers (e.g., 1), 2), etc.), which should then be explained at the end with the applicable note.



Project:

Date:

No.	GUIDELINES FOR THE ANALYSIS, CONSERVATION AND STRUCTURAL RESTORATION OF ARCHITECTURAL HERITAGE ICOMOS / ISCARSAH -INTERNATIONAL SCIENTIFIC COMMITTEE FOR ANALYSIS AND RESTORATION OF STRUCTURES OF ARCHITECTURAL HERITAGE **CHECKLIST FOR IMPLEMENTATION OF ICOMOS/ISCARSAH GUIDELINES**	Reference to the Guidelines section	Task completed				Further comments no.
			yes	no	tbc	n/a	
1	2	3	4				5
1	**ANAMNESIS: KNOWLEDGE ACQUISITION**	**2**					
1.1	**Historical research and documentation**	2.2					
1.1.1	A description and understanding of the structure's historical and cultural significance						
1.1.2	The original materials, construction techniques and skills used in its construction						
1.1.3	Subsequent changes in both the structure and its setting						
1.1.4	Historical natural actions (such as earthquakes) and the damage or collapses caused						
1.1.5	Events of anthropogenic origin (such as conflicts) that may have caused damage, failures, reconstructions, additions or changes						
1.1.6	Conservation works and structural interventions, structural modifications or changes of use						
1.1.7	Relevant data sources, standards and codes used during the construction period. Compliance with historical rules of art and codes can be considered for a preliminary appraisal of the adequacy of the structure's design, but further assessment is necessary						
1.2	**Inspection, surveys and investigations**	2.3					
1.2.1	Scope of investigation:	2.3.1					
1.2.1.1	*A detailed and accurate survey of the structure's geometry, including its deformed configuration, comprising all load-bearing and non-load-bearing elements, their connections and their construction features*						
1.2.1.1.1	Drawings in various appropriate scales (depending on the size of the structure)						
1.2.1.1.2	3D digital representations						
1.2.1.2	*A survey of the site, soil conditions, groundwater levels and environment*						

Project:

Date:

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			yes	no	tbc	n/a	
1	2	3	4				5
1.2.1.3	*Identification of any ongoing environmental and climate change effects*						
1.2.1.4	*Detailed survey of decay and damage (including alterations such as material disintegration, efflorescence, cracks, dislocations, deformation and other)*						
1.2.1.5	*Characterization of deterioration processes*						
1.2.1.6	*Presence of discontinuities within the structure*						
1.2.1.7	*Presence of structural links (contacts and connections) with neighbouring buildings*						
1.2.1.8	*Identification of the material types (for instance, stone and mortar types or wood species). Identification of original materials and repair ones along with their chronologies, when possible*						
1.2.1.9	*Determination of the materials' properties (chemical, physical and mechanical)*						
1.2.1.10	*Characterization of the internal morphology of structural members, including the identification of multiple leaves in walls, fillings over vaults and other hidden construction features* *Recognition of past structural interventions and identification of the historical damage (cracks, collapses…) and other problems (changes of use or functional modifications) that motivated them*						
1.2.1.11	*Identification of decorative elements supported on the structure, including their way of attachment or connections to it*						
1.2.1.12	*Historic work marks, symbols and other pieces of evidence that reveal construction details or chronology*						
1.2.2	Initial inspection by direct observation	2.3.2					
1.2.3	Elaboration of the investigation program	2.3.2					
1.2.4	Decisions on urgent actions	2.3.3					
1.2.5	In-situ and laboratory testing:	2.3.4					

Project:

Date:

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1	2	3	4				5
1.2.5.1	*Mechanical, physical and chemical properties of the materials*						
1.2.5.2	*Decay processes affecting materials*						
1.2.5.3	*Stresses and deformation in the structural members*						
1.2.5.4	*Internal morphology of the structural members (e.g., the presence and nature of interior rubble fillings in pillars or multiple leaves in walls)*						
1.2.5.5	*Presence of any discontinuities within the structure*						
1.2.5.6	*Connections and construction details*						
1.2.5.7	*Morphology of foundation and soil*						
1.2.5.8	*Full geotechnical characterization of the foundation soil*						
1.2.5.9	*Hidden damage behind plasters, decorative elements, etc.*						
1.2.5.10	*Dynamic properties of structure*						
1.2.5.11	*In-situ tests considered:*						
1.2.5.11.1	Non-destructive tests (NDTs)						
1.2.5.11.2	Minor destructive tests (MDTs)						
1.2.5.11.3	Destructive tests (DTs)						
1.3	**Monitoring**	**2.4**					
1.3.1	Static monitoring:	2.4.1					
1.3.1.1	*Structural parameters (such as displacements, rotations, crack openings, stresses, strains, etc.)*						
1.3.1.2	*Environmental actions (temperature, humidity, wind speed and direction, variation of groundwater level, etc.)*						
1.3.1.3	*Period of monitoring*						
1.3.2	Dynamic monitoring:	2.4.2					
1.3.2.1	*Periodical repetition of dynamic inspection*						

Project:

Date:

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1	2	3	4				5
1.3.2.2	*Threshold monitoring*						
1.3.2.3	*Continuous monitoring*						
1.4	**Application of structural analysis to anamnesis**	**2.5**					
1.4.1	Simplified model of the structure						
1.4.2	Preliminary structural analysis						
1.4.3	Identifying main structural features and vulnerabilities						
2	**DIAGNOSIS AND ASSESSMENT OF THE STRUCTURAL PERFORMANCE**	**3**					
2.1	**Aim of diagnosis and assessment of the structural performance**	**3.1**					
2.1.1	Targets to be considered:						
2.1.1.1	*Safety of people at risk*						
2.1.1.2	*Safeguard of valuable immovable cultural and artistic contents*						
2.1.1.3	*Integrity of the structure itself as a cultural heritage object with the least possible alterations*						
2.2	**Historical approach based on the investigation of the past performance of the structure**	**3.3**					
2.3	**Comparative approach based on the comparison of the structure being analysed with a number of similar structures whose behaviour is already understood**	**3.4**					
2.4	**Experimental approach consisting in the execution of on-site experiments aimed to measure load capacity of structural members**	**3.5**					

Project:

Date:

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1	2	3	4				5
2.5	**Analytical approach based on the use of structural analysis to predict the performance of the structure**	**3.6**					
2.6	**Model calibration**	**3.7**					
2.6.1	A visual inspection, allowing a comparison between damage that is numerically predicted under past actions and actually existing damage						
2.6.2	A characterization of structural past performance through detailed historical research and comparison with the corresponding model predictions. In particular, a study of past performance in the case of historical earthquakes						
2.6.3	Measurement and comparison of stresses at critical points under existing loads. Stresses can be experimentally measured by simple flat-jack tests in the masonry or hole-drilling tests in stone						
2.6.4	Dynamic inspection (identification), permitting characterization of dynamic properties (frequencies and modal shapes), and a comparison with an output of the modal analysis. This technique is conventionally known as “modal matching”						
2.6.5	Static monitoring, involving the characterization of actions (temperature, humidity, wind, microtremors) and response (cracks, displacements, rotations), and comparison with a simulation of the response of the numerical model subjected to the same actions						
2.6.6	A sensitivity analysis after model calibration, in order to evaluate the influence of the most relevant or least certain hypotheses (e.g., material data, connections) in the results						

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1	2	3	4				5
2.7	**Synthesis of approaches**	**3.8**					
2.7.1	Requirements						
2.7.1.1	*The consistency of information provided by different approaches, carefully investigated with the aim of identifying possible contradictions*						
2.7.1.2	*Completeness refers to the need to obtain the necessary reliable and sufficient information on relevant variables of the problem (including the characterization of the geometry, materials and actions, among other aspects)*						
2.7.1.3	*Corroboration, occurring when information provided by different approaches supports some evidence or conclusions in a redundant way*						
2.7.2	*Evidence obtained through different approaches satisfies the above requirements in an acceptable way (does not show unacceptable contradictions)*						
2.7.3	Verdict on structural performance, based on a synthesis of approaches						
3	**THERAPY**	**4**					
3.1	**Intervention criteria**	**4.1**					
3.1.1	Compatibility with original materials and techniques						
3.1.1.1	*Chemical compatibility*						
3.1.1.2	*Physical compatibility*						
3.1.1.3	*Mechanical compatibility*						
3.1.2	Durability						
3.1.3	Non-invasiveness						
3.1.4	Re-treatability						

Project:

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1	2	3	4				5
3.1.5	Removability						
3.1.6	Feasibility						
3.1.7	Controllability						
3.1.8	Sustainability						
3.1.9	Minimum intervention						
3.2	**Application of intervention criteria in practice**	**4.2**					
3.2.1	*Strategy of intervention*						
3.2.1.1	*Reinstating the capacity of part or all of the structural elements*						
3.2.1.2	*Insertion of new structural elements, compatible with existing ones*						
3.2.1.3	*Introduction of passive protection by means of dissipative elements and/or base isolation*						
3.2.1.4	*Mass reduction*						
3.2.1.5	*Limiting or changing the use of the building*						
3.2.1	Prioritisation of criteria						
3.3	**Repairability; pre- and post-natural hazards structural maintainability**	**4.3**					
3.3.1	Repairability						
3.3.2	Pre- and post-natural hazards structural maintainability						
3.4	**Proposed engineering approach for the design of the intervention**	**4.4**					

Project:

Date:

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1	2	3	4				5
3.4.1	Selection of alternative solutions that verify the adopted structural requirements, for further consideration						
3.4.2	Evaluation of the impact of alternative solutions in terms of loss of authenticity and heritage values						
3.5	**Structural analysis within the therapy phase**	**4.5**					
3.6	**Incremental approach**	**4.6**					
4	**CONTROL**	**5**					
4.1	**Professionals participating in the process possess the necessary qualifications**						
4.2	**Quality control assessment during intervention works**						
4.3	**Quality control assessment after intervention works**						
4.4	**Detailed maintenance plan**						
5	**EXPLANATORY REPORT**	**6**					
5.1	**Presentation of:**						
5.1.1	Reliability of data						
5.1.2	Uncertainties						
5.1.3	Hypothesis used						
5.1.4	Degree of caution exercised at each stage						
5.1.5	Alternative intervention solutions with the pros and cons of each						
5.1.6	Urgent works						

Project:

Place:

Client:

Date:

Prepared by:

No. GUIDELINES FOR THE ANALYSIS, CONSERVATION AND STRUCTURAL RESTORATION OF ARCHITECTURAL HERITAGE

ICOMOS / ISCARSAH

INTERNATIONAL SCIENTIFIC COMMITTEE FOR ANALYSIS AND RESTORATION OF STRUCTURES OF ARCHITECTURAL HERITAGE

CHECKLIST FOR IMPLEMENTATION OF ICOMOS/ISCARSAH GUIDELINES

Comments listed in column 5 and other: