

1 What is conservation engineering?

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Introduction

In the words of Sir Bernard Feilden, the conservation of historic buildings is a complex series of actions taken coordinately by several professionals in order to prevent the decay of a building while preserving and enhancing the cultural values embedded in it (Feilden, 2003).

The successful preservation of a historic building or environment, unless it has become a museum, depends on its continued use and the daily care and maintenance that come with this. The possibility of continued use depends on the adaptation of the building to present-day standards and ways of living, and in turn these invariably require changes in some of the constructional or structural features of the building. Conservation engineering can thus be defined as the branch of conservation that deals with managing the structural well-being of a building, minimising alteration and extending its life for future generations.

Structure is the prime determinant of a building's shape and hence it ultimately determines the building's aesthetic value, notwithstanding the frequent denial of structure that can be traced throughout the history of architecture (Warren, 2004). Structure is the skeleton on which the building's envelope is draped, with its architectural details, decorations and finishes. Hence it is essential to understand the structure and its condition in order properly to preserve the architecture.

The understanding of a structure comes from accurate analysis, whether numerical or qualitative or involving the study of historical records, in order to comprehend the evolution of its behaviour with time, to formulate a diagnosis relating to its current state and to forecast its future performance and thus devise appropriate measures of intervention.

This chapter attempts a definition of the boundaries and methodology of conservation engineering, a framework shared with the authors of subsequent chapters. Below is a very brief history of attitudes to structural intervention in historic buildings from our present perspective mainly based on the evolution of architectural conservation in Europe. There follows a description of the current approach to structural conservation on the basis of the two guiding, but sometimes conflicting, concepts of safety and authenticity. Specific reference is made to official international documents and guidelines. The relevance of the 'time' parameter in any conservation

strategy is then discussed and the chapter concludes with a brief review of the book's contents.

A very brief history of structural intervention in historic buildings

A keen interest in the repair and restoration of ancient buildings was expressed as early as the sixth century AD by the emperor Theodoric the Great, who appointed an *architectus publicorum* to oversee the restoration of all important civil structures in Rome, such as the city walls and aqueducts and the Colosseum, already the object of spoil and pillage (Jokilehto, 1999).

A more systematic interest in historic buildings can be traced back to Renaissance architects' studies and drawings of Roman ruins. Particularly interesting examples are the plan and elevation drawings and detail sketches of the Colosseum produced by Giuliano da Sangallo (*Codex Barberini*). While the elevation realistically depicts the state of ruin of the external wall, the plan is drawn as a circle rather than an ellipse, in a sort of idealised interpretation of the real shape. Renaissance architects, however, were interested not only in the proportions and decorative apparatus of Roman buildings but also in the materials and technologies used to erect them. These indeed had been proven successful in ensuring the survival for centuries of the feats of Roman engineering, notwithstanding the effects of war, abandon and natural hazard.

Further proofs of this interest in Roman technology are the wide popularity in the Renaissance of construction treatises such as Vitruvius's *De Architectura* and the fact that Roman construction practices were used in contemporary buildings. The accurate depiction of ruins in the drawings of engravers such as Maarten van Heemskerck and Giovanni Antonio Dosio allow us today to reconstruct the condition of important buildings in the sixteenth century and to formulate hypotheses on the causes and modes of their damage and destruction.

The first to write technically about the maintenance, restoration and consolidation of ancient buildings, using the same form of Vitruvian treatise, was Leon Battista Alberti in the last two chapters of his tenth book (Alberti, 1485, English translation published 1988). He used the medical analogy so popular today and advocated a thorough investigation of the causes of damage and decay before deciding on a course of action. However, it is only with Leonardo da Vinci at the beginning of the sixteenth century that the first accurate mechanical interpretation of structural work is presented, together with structural repairs and preventive measures.

Alberti and other contemporaries stressed the essential importance of continued use and maintenance for the preservation and good upkeep of even the best-constructed buildings. Alongside the development of these new ideas, common construction practice was to use the larger abandoned ancient buildings as quarries and reclamation grounds, either using architectural elements such as columns and capitals in new buildings, as

documented by Serlio, or using raw materials such as travertine, for instance from the Colosseum, in the production of lime.

At the beginning of the sixteenth century concern about the destruction of Roman heritage and antiquities resulted in the appointment of Raphael as Commissioner of Monuments, with the role of overseeing all activities connected to ancient ruins. This can be considered as the first step towards the modern involvement of the state in the protection of monuments. The interest in antiquities and historic buildings was exported to the rest of Europe, especially by the engravers and vedutists of the seventeenth century, and fascination with classical architecture was strengthened by the new ideas developed by the Enlightenment that led culture and science to become independent of religious beliefs.

In England the societies of Antiquaries and Dilettanti were formed around this time; these became forums for discussing the experiences and knowledge acquired during the Grand Tour, the journey through Europe lasting several years that travellers took to acquaint themselves with the architectural and artistic marvels of classical Italy and Greece.

Changes in Christian doctrines and liturgies, introduced by Lutheran reform and the Vatican counter-reform, had already led to substantial manipulation of both external and internal medieval church architecture throughout Europe. Architectural changes often revealed or highlighted structural problems, which were often recurrent and needed engineering solutions. One case in point is the celebrated report by Giovanni Poleni on cracks in the dome of St Peter's, Rome, in 1748. This is today considered to be the first attempt to apply rational analysis and an engineering method to explain the causes of an observed damaged state in an existing structure and to propose the least obtrusive intervention (Heyman, 1976).

In the United Kingdom the architectural alteration of churches often took the form of introducing classical architectural elements into Gothic structures, and the conservation movement evolved from the debate between the Neoclassical style and the Gothic Revival, crystallised in the repair campaigns carried out at Durham and Salisbury cathedrals at the end of the eighteenth century by James Wyatt and fiercely opposed by John Carter in the pages of the *Gentleman's Magazine*.

The concepts of reversibility and respectful treatment of works of art, and the importance of authenticity in the original piece as an embodiment of history, were first introduced during the eighteenth century in sculpture and painting repairs by Johann Joachim Winckelmann and Giovanni Pietro Bellori respectively. In Italy these concepts were also at the base of the approach to the restoration of architectural monuments, as demonstrated, for instance, in the work carried out by Raffaele Stern to stabilise the eastern end of the outer wall of the Colosseum in 1806. In this work all original parts, even those threatening collapse, were preserved and supported by a more modest, clearly different material that had a purely structural function, without any attempt to disguise the intervention, so that it should not be mistaken for part of the original. The result was very dramatic. However, just twenty years later this purist approach to structural repair was already diluted, mainly as a result of aesthetic criticism, as can

be seen in the second buttress at the western end of the external wall of the Colosseum, inserted by Giuseppe Valadier in 1825. Although fulfilling the same structural function, the two buttresses could not be more different in underlying conceptual approach to structural conservation (D'Ayala *et al.*, 1992).

In the United Kingdom, William Atkinson had an approach similar to Stern's. Realising the weathering vulnerability of the sandstone at Durham, he was the first to propose carrying out repair by using mortar mixes rather than substituting failed stone with new cut. He recommended the use of Parker's cement, a hydraulic lime obtained from the calcination of Bath stone and today better known as Roman cement. This approach to consolidation work was later retained in both the RIBA guidelines and the SPAB manifesto.

The two approaches outlined above were to a certain extent coexistent, and while very often guidelines and writings about the care of historic buildings in the early nineteenth century advocated a 'scientific' methodology respectful of the historic and archaeological value of the monument, actual practice entailed substantial demolition and reconstruction aimed at the glorification of a certain historic period and architectural style. In France especially, the style of choice was Gothic, which was considered the principal architectural heritage of the nation. Substantial work was undertaken on churches and castles, either because of the genuine need of remedial work or to remove additions from other periods, following the lines of 'stylistic restoration' historically associated with the figure of Viollet-le-Duc. While it is impossible to justify the relevance of Viollet-le-Duc's work in conservation policies and practice today, it is fair to say that his activity in France and his writings crystallised a certain ideal of restoration work, which, in his own words, consisted of 'reinstating a building to a condition of completeness which might never have existed at any given time' (Viollet-le-Duc, 1858–68) – that is to say, the restorer was allowed to create a historic falsehood in the name of stylistic unity. This falsehood was so much the greater for Gothic churches and cathedrals which had evolved through two or three centuries, from early Romanesque to late Renaissance, in terms of both style and construction.

From the point of view of structural conservation, the major contribution of Viollet-le-Duc is certainly his interest in and detailed study of medieval construction techniques and materials, and the recognition that architectural forms were a logical consequence of structural principles that depended, in turn, on the behaviour of the construction materials. In reintegration and repair Viollet-le-Duc advocated the use of the same material; however, new stone blocks were inserted in place of weathered ones, and in his later interventions he approved the use of steel in place of the original timber, with the same structural form and function.

In England during the same period, John Ruskin led a strong critical movement against stylistic restoration. More than anyone before him, Ruskin was concerned with the sense of history embedded in a weathered surface as the principal value of a historic building, together with its architectural composition and finishes; these he considered testament to the

process of creativity and hence to the authenticity of a particular building. Restoration therefore could only be seen as alteration to either the fabric or the architecture, and in any case was misleading. Much of his work was in defence of Gothic architecture, against the prevailing Neoclassical movement. However, in his later years he also had to speak against the deception produced by the Gothic Revival movement. As for structural intervention, he was in favour of introducing ties and anchors in buildings to stop cracks and the effects of movement, and to minimise intervention he was even in favour of permanent shoring as an alternative to rebuilding a part of a historic building or monument that was threatening collapse. The main objection of Ruskin's contemporaries was to his far too radical attitude, which if assumed as a rule would have led to many existing buildings becoming eventually unusable.

Eventually, it was Sir George Gilbert Scott's approach to historic buildings, as highlighted in a paper of 1862, that became the set of practical rules published by the RIBA in 1865 with the title *Conservation of Ancient Monuments and Remains*. This document not only provided the basic methodological and ethical approach to conservation but also established practice in terms of institutional and private involvement and the roles of the various professionals. Scott's paper was very influential in England and it still informs much of today's conservation practice.

A decade later, in 1877, William Morris founded the Society for the Protection of Ancient Buildings (SPAB) and issued a manifesto which declared maintenance and conservative repair to be fundamental conservation principles. Most importantly, it identified authenticity in a historic building as the original in situ material of any period and style over which the life of the building had spanned. Consequently, any substitution of old with new – or restoration – was clearly associated with loss of authenticity and value, and hence was banned. The SPAB was influential not only in the United Kingdom but across Europe, where its members engaged themselves in debate or denounced restoration work on major international landmarks.

Safety and conservation: a dichotomy?

In the present day, while different approaches are still predominant in different countries, the preservation of historic buildings is regulated worldwide by the Venice Charter issued in 1964. This was underwritten by representatives from sixteen countries forming the International Council on Monuments and Sites (ICOMOS). Since then many other charters have been published and many more countries have joined in. ICOMOS is funded by UNESCO, the organisation of the United Nations involved in education and cultural development across the world.

Current conservation engineering practice in the UK developed from several landmark projects carried out in the late twentieth century, including Ely Cathedral, York Minster and St Paul's Cathedral, and more recently Windsor Castle. It was the critical assessment of these projects and the

observation of their performance over several decades that led to the current paradigm; most importantly, there is recognition of the need for alternative analytical and assessment models which acknowledge the substantial difference in behaviour between traditional and engineered materials – masonry and timber as opposed to steel and reinforced concrete. The other strong influence on structural conservation is the increasing awareness of the vulnerability of historic buildings to natural hazards – earthquakes, fire and flood – and the need for damage mitigation strategies and strengthening interventions which will be respectful of the historic fabric.

All structural intervention should be governed by the four maxims of conservation first proposed by SPAB: *conserve as found*, *minimum intervention*, *like-for-like repairs* and *interventions should be reversible*. These also represent the current position of English Heritage and are at the core of British Standard 7913: 1998 *A Guide to the Principles of the Conservation of Historic Buildings*. In addition to the four maxims, this recommends that attention be paid to the effects of localised repairs on the overall structure, from both a physical and an aesthetic point of view, and draws attention to the question of whether it is acceptable that they should be seen and how easy it should be to identify them clearly. Similar principles to these form the basis of most historic buildings legislation in the western world.

Conservation engineering can be defined as the process of understanding, interpreting and managing the architectural heritage in order to *safely* deliver it to posterity. The term ‘safely’ is broadly taken to embody the concept that the bodies and individuals responsible for the care of historic buildings will work towards ensuring maximum private or public usability balanced against minimum loss of fabric and value. The safe use of the built environment is regulated by standards and codes of practice drawn up by competent institutions that assume as a point of reference a certain level of risk in society that is generally considered acceptable. The structural stability and robustness of a building is, however, only one of the elements defining its safe use.

The conflict between safety standards and conservation philosophy usually stems from the fact that not just the standards themselves but also the practice of achieving the standards are based on and refer to modern materials, technology and process. A historic building is considered of value not only because of its age but, most importantly, because of its uniqueness, its deviation from the norm and hence, to a certain extent, from what is standard. This constitutes the building’s significance or authenticity, a quality that it is vital to conserve.

Hence it would appear that the philosophical approaches at the basis of the two processes – ensuring safety and conserving a building – are at odds. This, however, is not entirely true, as construction historically was also regulated by standards and rules of practice, even if to a lesser extent and from a different knowledge base.

The task is to redefine the level of risk associated with the use of historic buildings that society is ready to accept in a trade-off for conservation, and to develop a different set of standards and processes to evaluate and ensure a building’s compliance. The development of a different set of

standards is clearly an operation that requires various elements of society and expertise to come together.

The process of assessing existing structures and buildings – not necessarily of heritage value – is a well-developed branch of civil engineering. This is called upon every time a change of use is proposed for a building or when an unexpected event occurs that may affect its structural stability and capability. However, the procedures and technologies developed for this purpose are in general designed to deliver compliance to the same standards that apply to new buildings.

The issue becomes a matter of whether the procedures and assumptions formulated by structural engineers for existing buildings can be successfully extended to historic buildings of heritage value, in the effort to ensure both safety and protection of the fabric. In these terms conservation engineering can be defined as the application of analysis and design techniques to the assessment of the structural capacity of elements or entire structures which may be archaic, obsolete or originally non-engineered (see also Friedman, 2001).

A 'safe' structure may be defined as one that will withstand the designed loads without becoming unfit for use, the judgement of safety being based on expected performance versus expected environmental and human actions. Most pre-nineteenth-century buildings were not designed to given structural standards, but rather to rules of thumb and general geometric criteria drawn from experience of collapses. This accumulated experience was ultimately based on past performance and its extrapolation to future behaviour for a given use. In this sense the present-day approach to structural design differs from the past only in so far as the evidence from experience has been codified, parameterised, rationalised – in short, it has been provided with a scientific basis.

The two design approaches – the traditional and the modern – differ not so much in their underlying process as in the method followed. This means that in principle modern codes are applicable to structures that pre-date codes, but that in practice, in order to really assess a historic building, the structural engineer needs to travel over the same path that led to the traditional accumulated experience; the engineer thus needs to possess both traditional building knowledge and current engineering knowledge. For this to be professionally practical, a robust method of acquiring that traditional knowledge needs to be devised which is applicable on a project-by-project basis and produces transferable know-how.

Formulating the safety judgement

In most cases a structural intervention serves either to repair so as to restore the original structural capacity, or to add strength to the existing capacity, or to provide an additional structural behaviour – for instance, lateral stability and strength to systems that might not have it. It is then reasonable to assume that the choice of materials, level of alteration, reversibility, even level of safety, should be guided by the type of interven-

tion – that is, whether it is repairing so as to restore or strengthening so as to add. This conceptual distinction between repair and strengthening can provide a robust framework of guidelines for enforcing compliance with present-day standards or, more appropriately, for defining a separate set of standards based on the concept of improvement of performance rather than compliance with the existing codes for new build.

The two issues outlined above – robust acquisition of knowledge and robust measurement of performance – have been thoroughly debated by professionals and academics over the past thirty years. A good example of the agreed body of knowledge and approach so far reached, at least as far as western culture is concerned, is contained in the document of recommendations produced by the ICOMOS International Scientific Committee for the Analysis and Restoration of Structures of Architectural Heritage (ISCARSAH).

The ISCARSAH principles identify a process – of anamnesis, diagnosis, therapy and control – that leads to a robust assessment of safety while safeguarding the fabric. This involves the collection of all relevant data, the identification of the relation between cause and effect, remedial measures and the monitoring of their effects. The approach is not dissimilar to that used in the assessment of existing modern buildings. What is different is the source of information, its interpretation and specifically how the final judgement on safety is arrived at. For historic buildings much of the information will be qualitative and anecdotal rather than quantitative and systematic. Can a judgement of safety be based on such data, and can such data be treated with the same tools with which engineers treat systematic quantitative data? In general, the present-day approach to safety involves an accepted level of uncertainty associated with any information on materials or structural performance; indeed, data is collected and processed so as to provide information with a given level of uncertainty which society assumes to be acceptable.

In the case of a historic or non-engineered building, the uncertainty of any data is variable and may depend on expert opinion. In other words, it will depend on how reliable the structural engineer considers that particular data to be and how confident he or she is in using it. The level of confidence will depend on the knowledge base available to the professional for the particular form of construction. This can be supplemented, when appropriate, with various non-destructive or semi-destructive diagnostic techniques, which will help to locate and identify pathologies and correlate them to plausible causes, but also assist the acquisition of information on the mechanical characteristics of the in situ materials.

On the basis of the information gathered, the engineer needs to consider, first, all feasible structural models with an explicit statement of how conservative each particular scheme is. Nowadays this activity can be aided by computer programs that allow relatively quick and synthetic results to be obtained for a relatively large number of initial hypotheses. In this way, different feasible structural behaviours can be investigated and corresponding safety factors estimated. However, it should be considered that to a certain extent the more complex the model, the less reliable are

the results, unless the model complexity is accompanied by a substantial reduction in the uncertainty of the initial data. Hence at each stage of the assessment the analysis should always be carried out by considering the simplest, most conservative model first, moving to more refined or complex ones only if there is not sufficient safety margin associated with it.

For structural models and analytical results to be of value to the conservation process, they need to include all the information associated with the structure that is not numerical or mechanical in nature. Hence the question arises of how qualitative knowledge can be translated into data fit for calculation. General guidelines for relatively simple conditions can be provided as follows:

- presence of cracks: reduction of redundancy; take into account that there is no transmission of forces along cracks
- presence of defects: reduction of capacity locally, for instance reduction of available cross section
- relative rotation between members: acknowledgement of type of connection, working of the joint

However, ultimately the use of qualitative information relies entirely on the capacity of the professional to interpret it correctly and translate it in structural terms.

Choosing an appropriate time frame

Once the phenomena affecting the historic building under assessment have been identified and possibly quantified, the final judgement on how safe the current conditions are and what is required to improve or extend that safety depends entirely on the engineer's perception of the evolution in time of such phenomena. Hence the time parameter, which has not been mentioned so far, is an essential variable of the problem of defining the interventions, both qualitatively and quantitatively. The time parameter affects all aspects of the conservation project:

- First of all, the expected remaining life of the structure.
- The expected interval of time until the next appraisal. Typically for churches and cathedrals this occurs every five years. This is also usually the case for public Grade I listed buildings, but not necessarily for minor architectural heritage, which typically gets reassessed every ten to twenty-five years depending on location and economic value.
- The expected life span of the intervention. Typically engineers design for a life span of fifty years for new buildings – both expected loading conditions and materials characteristics are defined for this life span.
- The variability in time of external loads and the risk associated with the occurrence of natural hazards. For ordinary construction, usually the design values chosen for natural hazards correspond to a given probability (typically 10%) of their not being overcome in the life span of the building (fifty years). For heritage buildings, especially those of great

importance, the tendency is to consider the worst possible scenario, usually determined by the worst event ever to have occurred in the region.

- Finally, the time frame of the project. Depending on what lead-up time to the intervention is available, monitoring of various time-dependent phenomena can be put in place, from which valuable information may be obtained. If the phenomena are highly important, the project schedule will probably need to be altered in order to allow for appropriate monitoring. Monitoring is also important during and after intervention, especially if this is to repair a defect, in order to assess the outcome of the intervention itself. Monitoring over time can also be used to gauge the magnitude and extent of any intervention.

Most importantly, the time parameter affects the whole concept of reversibility, and indeed reversibility is a fundamental principle of conservation. This is based on the observation that our present knowledge of structural behaviour and that of materials may be limited and that in the future, with further research and technological developments, better solutions might be found. At the same time, any intervention has to be durable; that is to say, its structural performance over the expected life span of the intervention should be more or less constant and reliable. Most durable materials usually lead to interventions that have limited reversibility. In this respect, the concept of retractability – falling just short of total reversal – may be more appropriate.

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