ABSTRACT

This article analyses the cultural and technical reasons which led to the widespread use of reinforced concrete in the restoration of historical monuments during the 20th century [1]. Mistrust in empirical techniques and the development of new safety concepts (based on models and quantifiable parameters), not only resulted in the responsibility for the safety of monumental buildings being attributed to structural engineers, but also meant new materials were applied as a new “technique” in all types of restoration. This coincided with the abandonment of the traditional art of construction and, at the same time, the progressive loss of research on masonry structures. A subsequent lack of knowledge was the premise for much of the restoration work with reinforced concrete carried out at the time. This research reviews this critical period to try to understand why and how certain restorations were conducted. The use of this new technique became the standard practice for repairing any form of deterioration in historical constructions, a fact which radically changed their structural conception for architects and engineers, consequently creating a different method of restoration. The subject of this research, therefore, does not only focus on technical motivations but also ideologies and social and economic motivations within the decision making process which led to the choices made.

INTRODUCTION

The subject of this research arose from the negative effects reinforced concrete had on restored historical buildings, which became apparent during the 20th century. The aim focuses on assessing the uses and effects of reinforced concrete as a restoration technique in heritage buildings. Interest for this topic derives from the observation that, over the last decade, much criticism has been made regarding the use and abuse of reinforced concrete in restoration. This criticism is both technical and methodological in nature. It became apparent that restoration work using modern materials, which had been considered very efficient, in some cases were not standing the "test of time". The technique displayed a clear incompatibility between original and restored elements due to its application, the quantity or quality of materials, and more importantly, because of inherent characteristics (i.e. problems of durability, reversibility and structural effectiveness). Also, recent seismic events have highlighted how, in many cases, the use of reinforced concrete has caused more damage to buildings than probably would have been caused without it having been applied.
The main objective of this research is to gain a greater understanding of the current condition of heritage buildings restored with reinforced concrete. This has been carried out by analysing the criterion of restoration and by evaluating, after approximately forty years, the effects of these actions. Documentation on such rectifications should serve as a means to re-evaluate traditional techniques, trying to evaluate why and how certain structural consolidation in different countries was carried out, to obtain a new understanding of restorations with concrete, and to lay the foundation for new lines of research into the proper use of both reinforced concrete and traditional materials.

This article is divided into three sections. The first section covers the reasons that legitimised the use of reinforced concrete and the crucial role the Athens International Conference, in 1931, played in supporting the use of reinforced concrete as a material for restoring monuments, showing enthusiasm for the new technique. The second section describes how, since the second half of the 20th century, the use of this technique has become the standard method to repair any form of deterioration in historical constructions. These restorations almost consistently typify the strategies adopted by countries within Europe, America and Asia. Finally, the third section analyses case studies of particular interest to restoration work in Italy and Spain, with a critical review on the disadvantages of employing reinforced concrete.

1. - CONCRETE IN THE FIRST HALF OF THE 20TH CENTURY: TECHNICAL & SOCIAL MOTIVATIONS

At the beginning of the 20th Century, huge changes to the structural construction of historical buildings began to be made which fundamentally influenced the way they were restored. As standard practice, traditional materials began to be replaced by a new material: reinforced concrete. This material was perceived as having favourable characteristics relating to resistance, durability and plasticity. Further, it was quicker to manufacture, easier to control and resulted in reduced costs. These other factors made it fashionable. Therefore, there were many reasons for its widespread use; not only social or historical factors but also, mainly, economical and technical ones. Blind faith in a new modern technique, resulted in traditional materials being abandoned, resulting in a loss of qualified workmen, and this was the reason why building and restoring masonry buildings with source materials (stone, brick, wood and limestone) became a thing of the past.

Ignacio Garate stated: “Since the beginning of the 20th Century the use of traditional materials, such as limestone has become obsolete, resulting in master artisans ceasing to exist, which intensifies the problem” [2]. Over time, knowledge of traditional construction techniques is being lost and the widespread use of reinforced concrete results in old practices being abandoned – stone buildings are no longer restored with stone. Another influential factor in introducing these new concrete reinforcements was to augment the strength of traditional structures perceived to have less stability and resistance. On the subject of the introduction of new materials D’Agostino commented: “reinforced concrete and steel, together with the theory of elasticity and a “rigid framework” in modern buildings meant that traditional constructions lost their sense of unity”[3]. In addition, S. Huerta established that “it is assumed that cracks in historical buildings pose an immediate threat to their stability, but this is not necessarily the case” [4]. On many occasions, cracks in historical constructions are one of the ways these buildings have to...
“protect themselves against/adapt to internal movements” producing articulations which enable them to move without collapsing.

Up until the second half of the 19th century the safety of buildings was determined empirically or entrusted to the experience and knowledge of the builders. However, this concept drastically changed, following new research based on scientific models and quantifiable parameters, affirming a new way of perceiving safety.

First restoration work using reinforced concrete

The first use of reinforced concrete in the restoration of historical buildings can be found in France, at the beginning of the 20th Century, then later in Italy. In France, the pioneer was Anatole de Baudot, pupil of Viollet-le-Duc and frequent collaborator with the French engineer Paul Cottacin. Baudot stated “new techniques should not be feared as they are based on a better construction system” [5]. By 1907 he was totally in favour of restoration work using reinforced concrete, and affirmed that “until these last few years restoration work has consisted of partial improvements, without real modifications being made. Nowadays, thanks to reinforced concrete, we are able to use a totally efficient solution. This wonderful technique will help preserve our buildings from the Middle Ages without their spirit being changed” [6].

The first ever restoration work, as understood in modern times, was carried out on the castle of Azay-Le-Rideau, France, in 1902, where the original wooden beams, without being removed, were carved out and consolidated directly on site using poured concrete and rebar in the cavities. This restoration was the starting point for a series of “experiments” carried out by Anatole de Baudot and his students, following which the French Commission of Historical Monuments decided to systematically adopt the use of reinforced concrete in the restoration of monuments. At the time of my research, I have found that prior to the work carried out on the castle of Azay, other French monuments had undergone restoration work using reinforced concrete. In 1860, Eugene Flachat strengthened the central tower of the “Catedral de Bayeux”.

Paul Gout (1880) repaired some frameworks with reinforced concrete in the “Mont Saint Michel”. Emile Brunet (1897) put a mesh of reinforced concrete on top of the vaults and strengthened the north portico of the “Catedral de Chatres”; and Anatole de Baudot (1899) strengthened the foundation of the church of “San Nicolás de Blois”.

Later, in 1905, Emile Brunet hung a cross of reinforced concrete in the “Catedral of Laon”. In 1906, Paul Gout placed a reinforced concrete beam between the two towers of the “Cathedral of Reims”, in order to unburden the underlying Gothic rose window. Between 1906 and 1910 the original roof in the Cathedral of Beauvais was replaced by a new structure with reinforced concrete.

These early restorations are all characterised by the fact they were local restorations, aimed at unburdening limited parts of the masonry structure with the insertion of a new structural concrete element, which usually worked as a beam. At the beginning, besides faith in the structural effectiveness, other technological factors played a part in the selection of reinforced concrete: for example, it allows longer spans which, by being poured into carved cavities, do not cause technical complications such as connections and joints. Further, it can be hidden within the masonry of walls and vaults.
The use of reinforced concrete in historical buildings in Italy, in particular, coincided with two events that concentrated on this new technique: the rebuilding of the bell tower of San Marco’s Venice between 1902 and 1911; and the earthquake in Messina-Calabria, in 1908. This solution addressed the seismic problems of the country.

The importance of rebuilding San Marco’s bell tower derives from the debate which preceded the work, involving many restorers and engineers from that period, and from the ensuing planning decision. Luca Beltrami was responsible for preparing the first proposal for reconstructing the tower. Following the criteria of “where it was and how it was”, the tower’s original fragments were carefully collected and put back together using existing documentation in rebuilding the original bell tower. The tower was completed in 1910 with a structure of reinforced concrete without plaster.1 The people involved in the restoration included Gaetano Moretti and the engineer Arturo Danusso. The latter was one of the leaders in restoration work using reinforced concrete in Italy during the 1930s.

The Messina earthquake of 1908 was a disastrous event. Many historical buildings were damaged or destroyed. Following the earthquake the engineers were organized for the first time to tackle the problem of the safety of buildings. The resulting response was to embrace reinforced concrete for use in the consolidation of existing buildings, as well as for the construction of new ones. Following the tragic seismic event, the first Italian seismic regulations came into force in April 1909. In title III, relating to the topic of repairs to traditional buildings it is stated that “buildings damaged and not built with a framed system, … must be strengthened with stanchions of wood, iron or reinforced concrete, fixed solidly into the foundations, continuous up to the top of the building and bound to one another by tie-rods at the offset floor of foundation, and to those of the roof and the eaves, in such way as to form a cage like bracing”.

The “Duomo di Messina” in Sicily, was heavily damaged by the earthquake of December 28, 1908. Francesco Valenti and Aristide Giannelli carried out the project of structural restoration with a solution based on the “total reconstruction of the work and prior demolition of all parameter walls which had supported the same”, replacing it with a new structure constructed with reinforced concrete to comply with the first seismic regulation of 1909.

The restoration work carried out in the area of Messina-Reggio Calabria contains the first references2 to the influences which generated the new seismic regulations for contemporary buildings; (i.e. the constructions of rigid frameworks using concrete). From then on a new structural guideline using reinforced concrete was incorporated into many historical constructions. The idea behind this selection was based on

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1 Following the collapse, a survey of all important buildings in Venice was immediately carried out resulting in temporary reinforcements in many cases. [7]
2 Francois Hennebique (1909) states in: “Reinforced concrete and earthquakes” in the society of engineers in Paris after the Messina-Calabria earthquake: few concrete buildings remain intact amidst a sea of ruin caused by the inability of the masonry buildings to withstand the horizontal force that an earthquake produces. He added, “these types of buildings are of a poor structure, the stone material used is almost always irregular and generally made up of pebbles, the mortar shows low consistency of lime and sand and the foundations do not belong to a strong system of construction, the roofs are generally defective as they lack technical hardening, there are few beams which connect the two ends so they work as a chain, and in the event of an earthquake, the heads of the beams do not detach from the edge and the roof collapses.”
“bringing consistency to masonry buildings and improving resistance to traction with new materials, to repair and prevent further damage” [8]. Some researchers consider that, in Italy, the concepts for the regulations on historical buildings were influenced through observing the damage caused to buildings after the seismic event in Messina and “for the first time procedures have been established in consideration of the structures in seismic areas” [9].

During the 20s and 30s, Ignacio Carlo Gavini played an important role in the technical and theoretical debate on the use of reinforced concrete in the restoration of Italian monuments. The first public declaration in favour of this technique can be found in an article of 1923 which states: “Now a new material has very successfully become part of the technical means available to the restorer.....Reinforced concrete may make solutions of innumerable problems easy, especially in earthquake zones..... today we have the means of being able to regain their beauty and give them a longer life” [10]. This technique became standard practice throughout Italy, one example can be found in Pescara, at the “Basilica San Clemente Casauria” (1919 - 1923). This restoration was carried out by Gavini and was based on reconstructing the missing parts with a new structure of reinforced concrete. These new elements could be appreciated at a simple glance, the observer being able to differentiate between the old and new. In this way it met the criteria of the 20s whereby the authenticity of the concrete material meant that the observer would not be deceived and would be able to recognise the added parts.

This empirical technique using reinforced concrete, during the first half of the 20th Century, also became a great resource in archaeological restoration throughout the Mediterranean, especially in Italy and Greece.

The main restoration technique used in archaeological areas was through *anastylosis*³, which consists of the consolidation of fragments, in an attempt to combine these to complete the element (i.e. columns, walls, portal, etc). This process is considered to be an example of pure reintegration, dependent on the discovery of original parts and knowing their exact location within the group. The use of concrete⁴, either reinforced or non-reinforced, was considered to be the main element able to recover and strengthen these structures.

One of the first, and most important, examples of anastylosis was the restoration work carried out on the temples of “Athenian Acropolis”, commenced by Nicolaos Balanos in the 30s. In 1931, Balanos, responsible for the work of the Parthenon, states that restoration through anastylosis, using reinforced concrete, has a great advantage: [it is] “discrete, proportionate and respected as a firm, solid, durable element”. This new criteria is based on the guidelines in the Athens Charter.

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³ According to M. López: “it is positioning the original shattered and scattered elements of a monument in their original place. It is the original unity coming together, rarely achieved due to the frequent disappearance of these elements...for those delicate, fragments or incomplete elements to be replaced methods of support, connection and supplement should be used. Portland cement is advantageous for various reasons, it accepts the necessary mass without affecting resistance, takes the colour of the dominating material, without being mistaken for it.” [11]

⁴ “Employing new pieces does not change the nature, provided that it represents a relatively small part of the group, it respects its shapes and dimensions and it differentiates between the original parts, for example, through the use of different materials such as concrete or brick”. [12]
The Athens Charter (1931) was the first international document for the protection of monuments. Clear technological matters in favour of the use of reinforced concrete were contemplated for the first time in this document. Article V states: “The experts heard various communications concerning the use of modern materials for the consolidation of ancient monuments. They approved the judicious use of all the resources at the disposal of modern technique and more especially of reinforced concrete. They specified that this work of consolidation should whenever possible be concealed in order that the aspect and character of the restored monument may be preserved. They recommended their adoption more particularly in cases where their use makes it possible to avoid the dangers of dismantling and reinstating the portions to be preserved”.

Reinforced concrete as a material for use in restoration was officially acclaimed during this International Conference in Athens, which clarifies the priority of the technical problem and, with trust and enthusiasm, acclaims reinforced concrete as a tool for the preservation of monuments. In general, there are two significant aspects that emerged from the talks; on one hand the technical exaltation of reinforced concrete; and on the other, in very few cases, the uncertainties and perplexities on the question of the formal aspects of restorations. The majority of speakers who participated in the conference showed their enthusiasm for this new material, as a unique resource for preserving heritage. One of them, the director of the “School of Architecture in Madrid”, Lopez Otero, considered reinforced concrete as the technique that best responds to the new criterion: “the triumph of this principle is reinforced concrete. There is no building that surpasses it, brings together the qualities of plasticity, adaptation, incombustibility and even economy. It also has another interesting quality, it behaves like a living being, which contracts to escape from excessive efforts making them migrate towards zones that are less stressed, in such way as to adopt, in the end, a perfect balance” [13]. Another person who ruled in favour of this new material was Gustavo Giovannoni “…this building process has the enormous advantage of plasticity, due to its nature of being a poured material, and rigid solidarity of the whole framework, obtained organically thanks to the internal bonding of the iron rods and the cohesion of the concrete” [14].

It is important to take into account that the first historical buildings which were restored with reinforced concrete “are carried out blindly and coincide with the success of modern construction, this trust in new technology results in some structural concepts in the restoration being surpassed” [15].

2. - REINFORCED CONCRETE (STANDARD METHOD & PRACTICE)

The immense destruction during the Second World War caused the use of reinforced concrete to peak and play an important role in the reconstruction of European heritage. The main reasons being: economy and the urgency at which monuments needed to be restored. Concrete structures are considered to be low cost, quick to build and structurally strong. It also has the advantage of having various uses on architectural elements such as: replacing original woodwork which has become detached from stone walls; strengthening structural elements such as arches, vaults, domes and towers heavily damaged by bombs; bracing and joining walls; and, through injections, stiffening the walls and deteriorated decorative elements. The versatility that this resource offered was favoured in the many reconstructions of damaged structures.
Among the main examples of reconstruction work in Italy: the church of “San Lorenzo Fuori le Mura”, in Rome, and the church of “San Francesco”, in Viterbo, in which an ingenious system of horizontal and vertical concrete elements were used to tighten and brace the walls. Another example is the bridge of Verona, which was reconstructed based on its original shape, whilst ornamental bricks were used to conceal the reinforced concrete structure. In a fourth example, the church of “Santa Chiara” in Naples remained badly damaged, and it was decided to empty the pilasters to relieve them of their structural function and to strengthen them on the inside with hidden concrete material. In addition the roof was reconstructed with a reinforced concrete framework.

In France, the building on which the most work was carried out with reinforced concrete after the war was “Catedral de Reims”. Henri Deneux used concrete to “recreate prefabricated elements in the roof; allowed easy mounting, to maintain the original aspect and lower costs, which had increased through the difficulty of obtaining wood”. Around 1200 wooden beams were replaced by prefabricated concrete beams and the pillars were strengthened by liquid cement being injected.

In Spain, one of the technical pioneers in the use of reinforced concrete in the restoration of historical buildings was the architect López Collado who introduced the concept that: “at present modern materials are available which can increase the duration of the monument and lengthen its life, that is why these materials are employed in concealed areas”. López Collado wrote the book “Ruinas en Construcciones Antiguas” (1974). This document became the manual for restoration referenced, from the 70s until the 90s, by the majority of universities and architects interested in the preservation of Spanish heritage buildings. It was one of the few documents in this era which suggested guidelines for the restoration of masonry buildings. Consequently, this book was widely circulated and greatly influenced the architectural restoration sector. Among the solutions it proposes are: 1) the use of concealed reinforced concrete to strengthen vaults and arches; 2) the introduction of concrete framing rings and metallic ties; 3) the insertion of concrete in stone pillars used as a formwork and 4) installation of concrete in the reinforcement of slab roofs and walls. With respect to wooden roofs it states that: “one should not rebuild the roof with another type of wood, having limited life and at risk of fire; rather we must replace it with other elements employing new procedures, such as reinforced concrete, these being more efficient and long lasting”. It also states that the introduction of reinforced concrete can be justified due to the fact that: it improves and ensures the permanency of the elements and the building easily adapts to these materials in its consolidation”. Importantly, it must be mentioned that it also states that although not essential, regardless of need or evidence of structural weakness: “reinforce concrete should always be used as a preventive measure, as by doing so we prevent future movement which may shorten the life of the building”.

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5 Gabriel López Collado, chief architect for the Service for Devastated Regions (1939-57) reconstructed a huge quantity of churches damaged during the Civil War, using concrete. At this time there were many technical and economical problems in carrying out urgent restoration work. As a consequence, many architects created multiple reconstructions with “more style and shape”, misunderstanding the stability of historical buildings. This coincided with the rest of post war Europe.
Main uses:
The most frequent uses of reinforced concrete in restoration are: in micro-pile for foundations; reinforced buttresses; core-filled injections with re-bar; framing rings; with wire mesh in the interior and exterior of vaults & domes; the reinforcement of arches and columns; and in rebuilding roofs with reinforced slabs.

The reason this technique became so successful in restoration when applied in the 50s in Europe and subsequently in the 60s in America and Asia was due to an excessive trust in concrete; a lack of a specific theory on its use; the influence of clear methods of calculation; and its perceived role as a signifier of technological advancement.

This is how new technology and scientific knowledge influenced and played an important role in the sudden use of concrete as the main technique of restoration during the 20th Century. The widespread use of this material by specialists as the primary resource to improve the structural integrity of historical buildings, based on new standards of safety, meant that traditional materials were abandoned and replaced by new reinforced concrete. Unfortunately, this moment significantly changed the design approach by architects and restorers due to their lost knowledge of the structural principles and construction methods used in traditional masonry buildings.

3. - CASE STUDIES AND NEGATIVE EFFECTS

The buildings restored during the 30s and 40s using reinforced concrete (Parthenon, Pompey and post war heritage buildings in France, Spain and Italy) began to reveal numerous pathological symptoms during the 80s and 90s.

In the specific case of Pompey at the end of the 20th Century, the Supervising Office of Archaeology and the Central Institute of Restoration began an in-depth investigation in order to comprehend the state of deterioration of three houses: “Guilia Felice”, “Dei Vetti” and “la Nozze d’Argento”. They analysed the replacement roof coverings which had been restored using reinforced concrete. At a first glance, problems were revealed

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6 Referring to the lack of theoretical principles, empiric restorations and application techniques.
due to the poor application of reinforced concrete and the adverse effects it had on the
original structures due to the added rigidness.

The majority of roof coverings restored with concrete were found to be in a bad state of
deterioration, due to three relating factors: (1) Environmental factors caused the rebar
to rust which was made worse by the lack of sufficient covering; (2) Inherent structural
design defects and mistakes made during the project, such as incongruent construction
techniques resulting, in some cases, in engineering factors including the under-sizing
and over sizing of concrete reinforcing; and, lastly, (3) the poor quality of the materials
used and inadequate maintenance.

The roof covering of “La Casa di Giulia Felice”, Pompey, restored with reinforced
cement during the 40s and 50s, was found in an advanced state of deterioration at the
end of the 20th Century, with detrimental evidence and corrosion of the reinforcing
rods. The roof was deflecting and required various props. Research was carried out
which confirmed: the precarious condition of the structure, low quality restoration,
lack of understanding of how concrete deteriorates, poor workmanship and inherent
structural design defects. For example, the amount of protective concrete cover around
reinforcing bars was often insufficient. Also the barrel vault of the thermal bath,
restored with concrete, showed signs of damage such as peels and cracks. Upon
analysing the damage it was decided that the concrete structure would be removed
where possible, and a new roof built similar in form and technique to the original.

An important discovery was made during the research in Pompey regarding the
durability and effectiveness of concrete as a material used in restoration in the 20th
Century. This was also expressed by D’Agostino: “the modern elements of reinforced
concrete now require immediate restoration differently from traditional elements; after fifty
years such restoration is inevitable, both due to the removal of the reinforced concrete structure
which is difficult to recover, as well as the safeguarding of other parts of the houses, the
preservation of which is jeopardised by the deterioration of said structure” [19].

Another archaeological area where the negative effects of the use of concrete could be
seen was in Ostia, Rome. During 2002-2004 strong deterioration could be seen in the
vaults, including: the disengagement between the original materials and concrete,
corrosion in the metallic elements, as well as evident cracks and fissures. One of the
reasons this damage became apparent was due to the iron rusting and carbonation
(gradient loss of alkalinity) of the concrete. Other damage could be seen in the upper
part of the walls where the technique of bauletti had been applied, which consists of
protecting archaeological remains through mixing Portland cement with various stones
such as pebbles and bricks. This added layer of cement began to separate, due to the
incompatibility between the host and new materials, as well as the formation of
vegetation around the bauletti and a great amount of salt and efflorescence.

Other case studies found the heritage restored during post-war in Italy and Spain, in
particular, the “Catedral de Tui”, Galicia, and the church of “Sant Doménech, Vic”,
were restored based on the exacerbated principles of the book “Ruinas en Construcciones
Antiguas” following the abuse of reinforced concrete.

In the majority of churches restored during the 70s and 80s in Spain the following
physical and chemical damage appeared: porosity, erosion between materials due to
freeze-thaw cycles, condensation caused by water vapour, iron rusting, carbonation of
the concrete, salts from Portland cement, efflorescence and the presence of alkali-aggregate reaction. The following mechanical incompatibilities could be observed: fissures and cracks due to the differences in rigidity.

Fig. 3 Ostia, Italy. 2004. The vaults show different types of damage caused from the physical, chemical and mechanical incompatibility between reinforced concrete and traditional materials. This damage includes rusting, protrusions and cracks.

Fig. 4 La Alambra, Granada, Spain. 2003. Damage caused by the encasement of elements using Portland cement carried out during the 1960s, incompatible with the traditional lime mortar used.

4. - ANALYSIS OF CURRENT CONDITIONS

Unfortunately, the durability of these restorations was not what was expected, and at the end of the 1980s a rapid process of deterioration became apparent in the work carried out with reinforced concrete. During the 90s, contradictory views began to be voiced regarding the way in which historical buildings should be restored. This resulted in various opinions being expressed regarding the problem.

On one hand the trend to recover traditional techniques and interpret the structural behaviour of historical buildings emerged. In this debate, the Italian engineer Antonino Giuffré tried to recover the artisan techniques which had already been forgotten and to work with traditional materials - avoiding the use of invasive methods or inadequate materials such as concrete and iron. Two conferences also focussed along these lines of rescuing traditional methods: (1) The ICCROM in Rome (1981) where, for the first time, specialist documentation appeared making reference to the problems Portland cement had in restoration work; and (2) in Salamanca (1984) where they researched the problems caused by altering stone and materials employed and concluded that: “Portland cement mortar is incompatible with lime mortar”.

On the other hand, in contrast to a return to traditional techniques and, on a larger scale, the new standard practice of using concrete continued without thought being

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7 Alberto Sepulcre states that: “for decades there has been an indifference to the knowledge of materials and historical construction techniques, perhaps because it was thought that the resistance and durability of reinforced concrete could effectively replace traditional materials or perhaps due to the disregard towards the predominance of these new materials.” [20]

8 An example of the criteria applied by Guiffrè in respect of traditional techniques can be found in the reconstruction of the brick vault of the “Catedral de Sant Angelo”, Lombardy, 1980
given to its suitability, **with a misplaced confidence in the technology.** Aldo Aonzo considered this material “as the instrument and defining technique in restoration, as a modern construction method, scientifically controllable and necessary for preservation”\(^9\).

In 1998, the Italian architect Paolo Marconi commented on one of the most used techniques of core filled injections in walls and vaults, stating “its durability is doubtful due to possible results which are more prejudicial than beneficial, for example the oxidation and disintegration of the rebar can affect the stability of the wall which is to be repaired” [22].

Another problem which was addressed in relation to this type of restoration, not only in Spain but in the majority of countries\(^10\), was that in nearly all cases the material was applied excessively, **more as a trend rather than a need.** This is how Javier Rivera expressed his opinion regarding the restoration work by Luís Cervera Vela on the “Catedral de Valladolid” in 1974, in which “they replaced parts which were not found to be excessively weak with reinforced concrete, as this was the trend in all Spanish cathedrals” [23].

At the end of the 1990s the number of specialists who advised against the use of reinforced concrete increased due to the constant problems it was causing and because they felt this technique was not as durable, compatible, reversible or authentic as originally had been expected in the restoration of old constructions. Antón Capitel, in reference to applying restoration techniques said “it is not enough to simply find an efficient technique and prevent the ruin of a monument; said technique must not be in contrast to the nature of its own technical values. An example of this can be found in the structural reinforcements made with concrete –the framing ring used in a gothic structure- may be an efficient technical solution but it would “betray” the original structural sense” [24].

**CONCLUSIONS**

At the beginning of the 21st Century, it became evident, on a wider scale, that the restoration work carried out with reinforced concrete, which was thought to be efficient, was not standing the “test of time”. The factor of time has been a primary element in understanding and evaluating the effects of reinforced concrete in restoration work, comparing the method’s effectiveness and use.

One of the main disadvantages of the concrete reinforcements is the properties of the material itself. We currently know that the durability of this material is less than previously expected. In addition the natural aging of concrete, the adaptation to environmental conditions and the resistance to the deteriorating agents (e.g. the carbonation and the insufficient layer of concrete cover) are causing severe problems in

\(^9\) A. Aonzo was the president of the Italian Technical Association of Cement when he wrote in the prologue of the book. [21]  
\(^10\) The standard use of reinforced concrete in restoration projects was not only employed in various countries, its maximum use spanned from 1960 to 1990. Therefore, I carried out extensive research within my doctoral thesis from the ICCROM files, in which it is stated that in almost all European countries, the majority of America, and some countries in Asia, the majority of **registered restorations were carried out using this technique** - proving the strong influence concrete had, which was applied as a simple restoration technique without there being in-depth knowledge of its behaviour or its possible effects, believing it to be the best solution in all cases.
the degradation of this material. In addition, concrete deteriorates much faster from the effects of external agents than traditional methods which have been well applied. In fact, lime used in a traditional way improves with the passing of time.

Therefore, **fifty years later**, the concrete reinforcements have proven to be less durable and compatible as was first anticipated, showing three types of pathologies: **physical**, **chemical** and **mechanical incompatibility**. In the analysis of cases in Spain and Italy, concrete showed signs of incompatibility with original elements, due to both the properties of the materials as well as mistakes in the work carried out, due to problems with the **technical execution**, quality or quantity of **concrete used**.

Conclusions from the case studies showed that the use of concrete reinforcements substantially **changed the behaviour of the original structures** due to the fact that they have different structural behaviours and, upon making them **more rigid**, these masonry buildings became **more vulnerable**, especially in seismic areas, as they were not able to absorb movement. The use of reinforced concrete had contributed to the damage caused to historical buildings, probably more than would have been caused without its “contribution”.

Other problems that showed this kind of restoration are due to the **authenticity** and the **difficult reversibility** between the concrete and the traditional materials.

After analysing the current situation in relation to concrete, we should begin to limit its use as a preservation technique and identify the correct choice of restoration materials and their suitable application in order to avoid major alterations having adverse effects on our heritage in the future. Other alternatives should be sought and not applied as global techniques but as potential solutions based on a **case by case**, thus replacing modern materials as a panacea for all restorations, changing the short-term actions and habits of those responsible for our heritage and introducing a methodology to analyse damage “in which there is a place for science, history and architecture in calculating the pros and cons of each of the alterations and modifications to be made to the original idea” [25]. To achieve this, **knowledge on traditional techniques** should be recovered and applied and a **better understanding** should be gained on the structural behaviour of **historical constructions**.

**REFERENCES**


