HISTORY OF CONSTRUCTION CULTURES

VOLUME 2

edited by
João Mascarenhas-Mateus
and **Ana Paula Pires**

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History of Construction Cultures

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Introduction: *History of Construction Cultures*

We are what we build and how we build; thus, the study of Construction History is now more than ever at the centre of current debates as to the shape of a sustainable future for humankind. Embracing that statement, the present work takes the title *History of Construction Cultures* and aims to celebrate and expand our understanding of the ways in which everyday building activities have been perceived and experienced in different cultures, times and places.

This two-volume publication brings together the communications that were presented at the 7ICCH – Seventh International Congress on Construction History, broadcast live from Lisbon, Portugal on 12–16 July 2021. The 7ICCH was organized by the Sociedade Portuguesa de Estudos de História da Construção (Portuguese Society for Construction History Studies – SPEHC); the Lisbon School of Architecture, University of Lisbon; its Research Centre (CIAUD); and the College of Social and Human Sciences of the NOVA University of Lisbon (NOVA FCSH).

This is the first time the International Congresses on Construction History (ICCH) Proceedings will be available in open access format in addition to the traditional printed and digital formats, embracing open science principles and increasing the societal impact of research. The work embodies and reflects the research done in different contexts worldwide in the sphere of Construction History with a view to advancing on the path opened by earlier International ICCH editions. The first edition of ICCH took place in Madrid in 2003. Since then, it has been a regular event organized at three-year intervals: Cambridge (2006), Cottbus (2009), Paris (2012), Chicago (2015) and Brussels (2018).

7ICCH focused on the many problems involved in the millennia-old human activity of building practiced in the most diverse cultures of the world, stimulating the cross-over with other disciplines. The response to this broad invitation materialized in 357 paper proposals. A thorough evaluation and selection process involving the International Scientific Committee resulted in the 206 papers of this work, authored by researchers from 37 countries: Australia, Austria, Belgium, Brazil, Bulgaria, Canada, China, Dominican Republic, Ecuador, Egypt, Estonia, France, Germany, India, Iran, Ireland, Italy, Japan, Mexico, Netherlands, New Zealand, Norway, Peru, Poland, Portugal, Puerto Rico, Russia, Serbia, Spain, South Africa, Sweden, Switzerland, Thailand, United Arab Emirates, United Kingdom, United States of America, and Venezuela.

The study of construction cultures entails the analysis of the transformation of a community's knowledge capital expressed in the activity of construction. As such, Construction History is a broad field of knowledge that encompasses all of the actors involved in that activity, whether collective (contractors, materials producers and suppliers, schools, associations, and institutions) or individual (engineers, architects, entrepreneurs, craftsmen). In each given location and historical period, these actors have engaged in building using particular technologies, tools, machines and materials. They have followed specific rules and laws, and transferred knowledge on construction in specific ways. Their activity has had an economic value and belonged to a particular political context, and it has been organized following a set of social and cultural models.

This broad range of issues was debated during the Congress in general open sessions, as well as in special thematic sessions. Open sessions covered a wide variety of aspects related to Construction History. Thematic sessions were selected by the Scientific Committee after a call for proposals: they highlight themes of recent debate, approaches and directions, fostering transnational and interdisciplinary collaboration on promising and propitious subjects. The open sessions topics were:

- Cultural translation of construction cultures: Colonial building processes and autochthonous cultures; hybridization of construction cultures, local interpretation of imported cultures of building; adaptation of building processes to different material conditions;
- The discipline of Construction History: Epistemological issues, methodology; teaching; historiography; sources on Construction History;
- Building actors: Contractors, architects, engineers; master builders, craftspeople, trade unions and guilds; institutions and organizations;
- Building materials: Their history, extraction, transformation and manipulation (timber; earth, brick and tiles; iron and steel; binders; concrete and reinforced concrete; plaster and mortar; glass and glazing; composite materials);

– Building machines, tools and equipment: Simple machines, steam operated-machines, hand tools, pneumatic tools, scaffolding;
– Construction processes: Design, execution and protective operations related to durability and maintenance; organization of the construction site; prefabrication and industrialization; craftsmanship and workshops; foundations, superstructures, roofs, coatings, paint;
– Building services and techniques: Lighting; heating; ventilation; health and comfort;
– Structural theory and analysis: Stereotomy; modelling and simulation; structural theory and structural forms; applied sciences; relation between theory and practice;
– Political, social and economic aspects: Economics of construction; law and juridical aspects; politics and policies; hierarchy of actors; public works and territory management, marketing and propaganda;
– Knowledge transfer: Technical literature, rules and standards; building regulations; training and education; drawings; patents; scientific dissemination, innovations, experiments and events.

The thematic sessions selected were:

– Form with no formwork (vault construction with reduced formwork);
– Understanding the culture of building expertise in situations of uncertainty (Middle Ages-Modern times);
– Historical timber constructions between regional tradition and supra-regional influences;
– Historicizing material properties: Between technological and cultural history;
– South-South cooperation and non-alignment in the construction world 1950s–1980s;
– Construction cultures of the recent past: Building materials and building techniques 1950–2000;
– Hypar concrete shells: A structural, geometric and constructive revolution in the mid-20th century;
– Can engineering culture be improved by construction history?

Volume 1 begins with the open session "Cultural translation of construction cultures" and continues with all of the thematic sessions, each one preceded by an introductory text by the session chairs. The volume ends with the first part of the papers presented at the open sessions, organized chronologically. Volume 2 is dedicated to the remaining topics within the general themes, also in chronological order.

Four keynote speakers were chosen to present their most recent research results on different historical periods: Marco Fabbri on "Building in Ancient Rome: The fortifications of Pompeii"; Stefan Holzer "The role of temporary works on the medieval and early modern construction site"; Vitale Zanchettin "Raphael's architecture: Buildings and materials" and Beatriz Mugayar Kühl "Railways in São Paulo (Brazil): Impacts on the construction culture and on the transformation of the territory".

The editors and the organizers wish to express their immense gratitude to all members of the International Scientific Committee, who, despite the difficult context of the pandemic, worked intensively every time they were called on to give their rigorous evaluation of the different papers.

The 7ICCH was the first congress convened under the aegis of the International Federation of Construction History, founded in July 2018 in Brussels. Therefore, we are also very grateful to all the members of the Federation, composed of the presidents of the British, Spanish, Francophone, German, U.S. and Portuguese Societies and its Belgian co-opted member. A special thanks is due for all the expertise and experience that was passed on by our colleagues who have been organizing this unique and world significant event since 2003, and in particular to our predecessors from all the Belgian universities who organized 6ICCH.

The editors wish to extend their sincerest thanks to authors and co-authors for their support, patience, and efforts. This two-volume work would not exist but for the time, knowledge, and generosity they invested in the initiative.

Our sincere thanks also go out to Kate Major Patience, Terry Lee Little, Kevin Rose and Anne Samson for proofreading every paper included here, and to the team at Taylor & Francis (Netherlands), in particular Germaine Seijger and Leon Bijnsdorp.

Finally, we are grateful to all members of the Local Committee and to the institutions that have supported both the 7ICCH event and the publication of these proceedings.

The Editors
João Mascarenhas-Mateus and Ana Paula Pires

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

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Open session: Knowledge transfer

History of Construction Cultures – Mascarenhas-Mateus & Paula Pires (eds)

Rebuilding after the earthquake: Earthquake-resistant construction techniques in Sicily in the 18th and 19th centuries

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ABSTRACT: This essay attempts to offer a contribution on earthquake-resistant techniques employed in Sicily between the 18th and 19th centuries through a comparative study of construction practices after three earthquakes: that of 1726 in Palermo, that of 1818 in the Etna area, and that of 1823 in the northwestern part of the island. Research is based on a cross study of iconographic and bibliographic sources (manuscripts, printed works by coeval authors, and treatises), and new archival documents, which provide general views of damage to towns hit by earthquakes, as well as many expert analyses of individual architectures. An analysis of certain case studies and the systematic study of sources, integrated with inspection of the sites, will make it possible to analyse the technologies applied to consolidate and restore buildings. The paper also shows persistence and innovations, that contribute to outlining the development of an earthquake-resistant technical culture.

1 INTRODUCTION

Sicily is a notoriously seismic area, and earthquakes were – and are – a recurring aspect of its history, as documented by historic seismology.

Over the years, the answer to natural disasters has differed, depending on a range of factors: identity of places; extent of damage; availability of economic resources; materials and craftsmen; and the building techniques used. The cultural orientation of institutions, administrative management, and efficacy of legislative tools were also factors.

When exploring reconstruction of architectural heritage, earthquakes have represented an opportunity to get to know the buildings, as these assessments are almost always accompanied by surveys and experts' reports that evaluate damage and also often include reflections aimed at experimenting in the field of construction.

The reinterpretation of traditional construction practices by architects and workers, which has often accompanied post-earthquake reconstruction, has frequently been linked to an attempt to innovate techniques, materials and means of reinforcement from an anti-seismic perspective. These efforts also served to encourage regulatory bodies to draft rules, as well as technical regulations, as evidenced by the many reconstruction regulations that are issued after an earthquake occurs. The awareness that earthquakes can be repeated over time has, in fact, also led to steps being taken in the field of prevention, as well as developing strategies and techniques to mitigate the seismic vulnerability of buildings. This has given rise to the most recent technical and regulatory tools that call for architectural adaptations and improvements of a monumental and strategic nature.

We will try to verify if there have been any advances and forms of experience sharing among different periods, by comparing the construction practices adopted in the reconstructions after the earthquakes on 1 September 1726 in Palermo, 20 and 28 February 1818 in the Etna area, and 5 March 1823 in the northwest area of Sicily.

The research task has been undertaken by studying both bibliographical sources, - with particular reference to printed texts by contemporary authors and treatises – and iconographic and archival sources.

The analysis of this readily accessible documentation has made it possible to gain a deeper knowledge of the main types of damage and the consequent reinforcement and reconstruction interventions on buildings as related to the definition of anti-seismic design criteria.

2 POST-EARTHQUAKE INTERVENTIONS ON ARCHITECTURAL HERITAGE - BETWEEN TRADITION AND INNOVATION

When faced with the problem of how to deal with a building damaged by earthquakes, historically two paths have been taken: on the one hand, demolished pieces are repaired or reconstructed, revamping preexisting traditional techniques, geometries and materials; on the other hand, an attempt is made to experiment and, consequently, innovate techniques (both materials and reinforcement elements) aimed at giving buildings greater resistance. This second path, explored here through the analysis of some case studies, has helped to define an evolution of building practices, based on verifying how effective certain solutions have been in the face of seismic events.

2.1 *Iron corbels, tie rods and hoops*

In 18th- and 19th-century Sicily, some attempts at seismic 'improvement' were often associated with iron devices, such as the introduction of metal chains and hoops. These techniques were employed in order to absorb thrusts and provide more effective connection among resistant elements to prevent them from falling outside the floor. This material was also used for cantilevered elements (Scibilia 2020).

The criteria identified for suitable reconstruction involved the combination of stone with other materials, the first of which was specifically iron which had been identified as an essential instrument to confer solidity and resistance on buildings. Though more rarely, wood, which is highly appreciated due to its properties of elasticity and lightness, was also used (Scibilia & Campisi 2016).

In reconstruction after the 1726 quake, the iron chain and hoop technique was perfected considerably and systematically applied to a large number of buildings, both monumental and traditional, setting the benchmark for subsequent construction works in cities (Scibilia 2020).

Sources testify that a few days after the earth-quake, the Tribunale del Real Patrimonio, the supreme administrative body of the kingdom, issued a dispatch (10 September 1726) that provided instructions regarding emergency management and included requirements related to reconstruction, such as forbidding stone corbels in balconies and ordering balconies to be reconstructed using iron corbels and slate sheets (so-called 'balate' or 'Genoa stone'). This provision was contrary to local traditions, according to which balconies were made using exposed stone corbels, stone balustrades acting as railing and sheets used as flooring; all of these were elements that, since the last quarter of the 16th century, had strongly characterised the façades of the city's aristocratic palaces (Fatta 2002). This provision stemmed from the awareness that stone overhangs were fragile elements, and it can be considered as one of the first anti-seismic regulations in Sicily.

The adoption of metal chains and hoops became widespread in the reinforcement of vaults and domes, which, as it is well known, are characterised by a high degree of seismic vulnerability. In these elements, damage was suffered not only by the dome shell, which often presented deep cracks, but also by the underlying wall structures, the inadequacy of which was mostly caused by insufficient dimensioning. The most frequent intervention on domes involved inserting hoops surrounding the whole perimeter of the dome shell; whereas, in the arches, chains were positioned at the springer or at the reins.

Taking into account the documentary evidence found and inspections carried out on a series of buildings, it can be inferred that the chains and metal hoops belonged to different types: in the case of chains, a distinction was made regarding the presence of either single-bar elements or several bars put together in order to reach the desired length. Other differentiating criteria concerned the section (square or round) and the type of joint (Fatta 1993). Hoops, on the other hand, were made of circular or square (*quadralino*) section bars that had shaped ends or eyelets or, according the terminology of that time, *bocca di lupo,* i.e. having an end slot and connected with each other by means of the insertion of pins or sticks. Alternatively, hoops were characterised by flat iron reinforcements (*righetti o righettoni*).

Archive documentation has permitted further investigation of some monumental buildings in Palermo in which iron was widely used after the 1726 earthquake, as demonstrated by the cases of the Royal Palace, the Cathedral and the Church of SS. Salvatore.

In the Royal Palace, according to the report written by the engineer of the Royal Court, Giuseppe Mariani (8 October 1726), the introduction of a large number of iron chains located in different parts within the architectural complex was proposed; this included the Palatina Chapel where the dome was reinforced with metal hoops, for which the report written by Giuseppe Furceri, master builder of the Royal Court, specified the conformation of the elements and the connection system (National Archives of Palermo-ASPa, *Conservatoria*, b. 2452, fasc. 37, c. 1r).

Iron chains were also used for reinforcement work on the cathedral, designed by Giovanni Amico, who, in 1725, already held the prestigious position of engineer of the *Tribunale del Real Patrimonio* for the whole of Sicily. The intervention on the dome, described in four surveys drawn up once the works were completed (all of them dated 15 October 1729), provided for the construction of "different chains, *stanghetti*, *cugni*, *gaffe*, long pins, hoops and other things that were necessary for repairing the devastation caused by the earthquake" by the *ferraro,* Giovanni D'Angelo. These were placed on the roof, in the steeple behind the tribune, and in the chapels of Nostra Signora Libera Inferni and of San Francesco di Paola, in the northwest part of the church. Additional metal tie rods were employed when reconstructing the upper part of the bell tower where oak-wood chains were also inserted (ASPa, *Notai defunti*, Giuseppe Magliocco, vol. 5223, cc. 156r-157r).

Among the different buildings mentioned, the church of SS. Salvatore is particularly interesting due to the substantial use of iron in the reinforcement works. During the earthquake, the building suffered considerable damage in several parts, including the dome, which it was suggested should be demolished and then reconstructed. This recommendation, however, was rejected, given the fact that the intervention was expected to be more expensive than the insertion of iron hoops and tie rods, according to the

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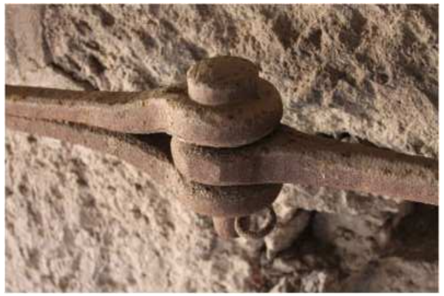

Figure 1. Palermo, Church of SS. Salvatore, detail of the connection system of the chain.

influential architects, Giacomo Amato and Gaetano Lazzara, who were asked for their opinion (ASPa, *Corporazioni religiose soppresse*, SS. Salvatore, vol. 843, cc. 116r-122v; Nobile 2004, 158; Scibilia 2015, 96-97). The works, which were carried out by *fabermurarius,* Simone Marvuglia, entailed the introduction of a large number of iron chains, consisting both of bars (*a braca*), and flat iron reinforcements (*a fascio*) for the hoops. The metal tie rods – the length and manner of preparation of which were specified – were placed at the arches limiting the main chapels and the choir, in the sacristy, at the corners, which were at risk due to the frequent lack of toothing in the intersection of walls, on the floor and in other, different parts of the building.

The chains were characterised either by single-bar tie rods (such as at the springer of the arches in the chapels) or by several square section bars that were put together. In the latter case, the end of one of the bars was made up of a simple eyelet while the end of the other one was characterised by a bifurcation; they were connected to each other by locking pins (Figure 1).

Such a system is the one that Jean Baptiste Rondelet, in his treatise, *Traité theorique et pratique de l'Art de Bâtir* (1802), would subsequently call a 'hinged' union, as exemplified by Figure 1 of table CXLVIII, contained in volume III, tome III, in which the adoption of iron reinforcements is shown.

In this type of connection, "the end of one of the bars forms a fork in which the end of the other bar is introduced. The three iron elements put together are perforated by a hole; through this hole, either a screw bolt or a key and some double wedges are passed" (Rondelet 1802, 59).

In the Church of SS. Salvatore, the iron hoops placed at the base of the dome along its perimeter are made up of round bars having slots at their ends so that the locking system can be inserted. Such a system consists of metal wedges, which pass through several chains and continue inside the stone buttresses (Figure 2).

The hooping system, placed at the springer of the small domes located at the main dome and at the tribune, is different; such hoops are made, in most cases,

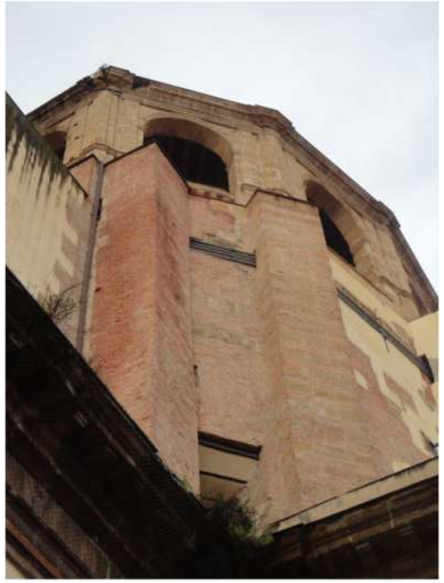

Figure 2. Palermo, Church of SS. Salvatore, hoops placed at the base of the dome.

with flat iron bars connected to each other by means of pins.

Even though the adoption of iron tie rods and hoops did not represent a novelty in the local context, as is demonstrated by their use before 1726, the earthquake constituted the perfect occasion to implement knowledge, to verify the choices that had been applied so far, to spotlight critical aspects and to take corrective measures.

The experience gained in the field of construction in this occasion was used after the 1818 and 1823 earthquakes, as indicated by express reference made to the measures and solutions tried out after 1726.

In relation to the quake that struck the Etna area between 20 and 28 February 1818, there are documented records of wall cross connection interventions by means of the insertion of iron chains, such as the ones foreseen in a private house in Catania by Antonino Battaglia, who indicated the placement of tie rods 'in a square', i.e. perpendicular to each other, and reinforcement of domed structures with metal hoops. This was done in the Church of San Michele Arcangelo in Catania, an intervention designed by Battaglia himself, and in the Church of San Giacomo in Aci Sanfilippo, where Salvatore Zahra Buda, head of the Catania Commission for Earthquakes, appointed by the Intendant of Catania, intervened (Lo Faro & Salemi 2009; Lo Faro, Mondello & Salemi 2018).

Iron chains were frequently used to reinforce bell towers, whose slender elements exposed them to greater seismic vulnerability. The use of metal tie rods is documented in the bell tower of the Basilica of San

Sebastiano in Acireale, where the structure was reinforced with a mesh of iron chains which was also used to reinforce the roof vault of the church at the central nave. A similar intervention was also carried out in the south bell tower of the Mother Church of the same city. This intervention, designed by engineer Giovanni Maddem, also included an increase in the resistant wall section (National Archives of Catania-ASCt, *Intendenza Borbonica*, b. 1159, cc. n.n.) which will be mentioned again further on.

As regards the 1823 earthquake, some reflections related to the use of iron can be traced back to Carlo Dolce, engineer of the Civil Engineer Corps and author of a text contemporary to the seismic event which contains considerations of a technical nature. Dolce approved the use of metal chains, which he considered necessary in order to make up for the "lack of tenacity and linkage in the different parts making up our buildings" (Dolce 1823, 35-36). However, he stressed the need to use them properly, both in relation to the positioning of the bars – to be carried out in such a way as to hold up the entire thickness of the masonry – and the adoption of a means to delay or prevent oxidation. In spite of the fact that the author did not specify such means, the methods used to counter iron oxidation were known and, in some cases, indicated by the writers of treatises. Some examples include the use of carbon black dissolved in linseed oil, as suggested by Francesco Milizia, or the method indicated in the subsequent treatise by Francesco Masciari Genoese, which recommended that "the iron used in walls should be previously coated with minimum on two occasions, or immersed in a cast lead bath…" (Masciari Genoese 1915).

Additional indications related to the use of metal elements were included in the "damage comparison charts" aimed at systematically identifying all the damaged buildings within each town; these "charts" constitute one of the most interesting documentary sources. In the "chart" corresponding to Monreale, which was drawn up after 13 March 1823 (ASPa, *Intendenza*, b. 7, cc. nn.), for example, it is possible to see that the most frequent reinforcement action consisted of the insertion of iron chains. The lengths, as well as the exact positioning and shape of the anchor plates – which always belonged to the Y-type (the so-called *a orecchie di lepre* or "hare ears") – of these chains were specified. Such a technique was adopted in Monreale for reinforcing not only several houses of private citizens, but also some monumental buildings such as the Monastery of the Benedictine Fathers, the Monastery of San Castrense, the Church of Monte di Pietà and the Archiepiscopal Seminary.

2.2 *Reed and plaster vaults and domes*

Among the innovations resulting from anti-seismic focused reflection on local construction criteria, we can mention the construction of reed and plaster vaults and domes, which were characterised by a

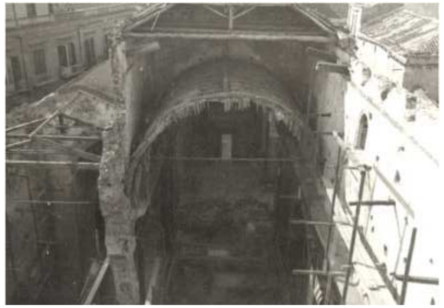

Figure 3. Rib vault in the church of St. Francis of Assisi in Palermo, revealed by the destruction caused by the 1943 bombings (Archive Soprintendenza per i Beni Culturali e Ambientali di Palermo. By courtesy of Assessorato regionale dei Beni Culturali e dell'Identità siciliana. Dipartimento regionale dei Beni Culturali e dell'Identità siciliana).

self-supporting structure independent of the overlying wooden frame. The construction of these elements using light material was, in fact, a valid alternative to the consolidation of real vaults with iron hoops and tie rods, although the adoption of metal elements was also privileged in order to guarantee the preservation of the dome outside the building.

Although this technique had been adopted previously, for example, in Abruzzo after the 1703 earthquake (D'Antonio 2013, 99-109), in Sicily, one of the first documented cases of this construction system is the reconstruction of the dome of the Church of San Carlo alla Fieravecchia after the 1726 earthquake. On this occasion, the original dome shell, dating from the first half of the 17th century, made in freestone and covered by a Lombard-style lantern tower with an overlying small lantern, was demolished and rebuilt with a light structure that weighted considerably less than a real stone structure. The documentation proves the construction of a 'false' shell, a so-called rib vault (*a incannucciato*), consisting of a wooden supporting frame, made up of poplar ribs and large reeds (*cannoni*), placed on the intrados of the wooden deck to which it was nailed and covered with lime and plaster mortar (Nobile 2004, 158–159).

It was probably after the discussion that started in Palermo following the 1726 earthquake that Noto-born architect, Rosario Gagliardi, the undisputed protagonist of the long reconstruction season following the 1693 earthquake in Val di Noto, chose to adopt such a solution to reconstruct the roof vault of the Church of Santa Chiara in Noto (1735), designed and built with an oval vaulted structure crafted from wood, reeds and plaster.

A similar system was used by the same architect in the oval vault of the Church of San Michele Arcangelo in Sicicli (1750), as he was aware that this kind of structure was more effective in the event of an earthquake (Nobile 2012, 20).

Similar structures were adopted in the Etna area as certified and documented, among other cases, by the reconstruction of the reed and plaster vaults of the dormitory of the Benedictine Monastery in Catania, damaged by the 1818 earthquake (Lo Faro & Salemi 2009, 115).

On this occasion, a similar criterion was applied when reconstructing the *Loggia Giuratoria* in Acireale, where the vaults called *mazzacannate* (made of stone) were discontinued and replaced by false vaults (Municipal Historical Archive of Acireale, *Court of jurors*, Acts of Liberation, vol. 25).

Also, after the 1823 earthquake, a similar intervention was used to restore the Church of St. Francis of Assisi in Palermo (Scibilia 2016, 177–178). For this church, there is a report prepared by the court engineer, Giuseppe Patti, who was commissioned by the Chapter house of the convent to detect any instability and to suggest the appropriate "restoration" (Rotolo 1952, 159-60). For the 16th-century stone vaults, demolition and subsequent reconstruction were planned with 'false' rib vaults both in the central nave and the side aisles, a system that, in addition to reducing the weight of the structure, also had economic advantages. The reconstruction with light vaults, actually carried out later (Figure 3), was also approved by court engineers, Luigi Speranza and Giuseppe Truglio, who, summoned by the convent fathers to give a second opinion, confirmed the validity of this solution.

The works on the church, carried out between 1824 and 1837 under the direction of several architects, involved building barrel and cross rib vaults matching, respectively, the central and side aisles, linking the foundation pillars, and their coating with *balatoni* (ashlars 'palms' measuring 2 x 2 x 1, where one palm is approx. 25.8 cm) from the Aspra quarries, turning the pointed arches of the main nave into round arches by means of lining with *pantofali* bricks (11 × 23 × 1.5 cm) and the reconstruction of the triumphal arch (Tinaglia 2005).

2.3 *Stone chains*

The search for alternative solutions for the reinforcement construction practice as a response to seismic events is evidenced, among other examples, by the original proposal developed to reinforce the Cathedral of Palermo by Amico, whom we mentioned above. One of the four reports written by the architect on the interventions carried out in the church – whose roof had been seriously damaged by the fall of the crenellations of the crowning – speaks of the adoption of "30 chains of 'Palazzo di Trapani' stone made in a doubled dovetail by the masters of that city", that is, stone "chains" shaped as a double dovetail (ASPa, *Notai defunti*, Giuseppe Magliocco, vol. 5223, cc. 158r-159r). The document does not specify the positioning of these elements, but their use is significant as an experimental intervention for the construction sites of the time. The hypothesis that this technique was foreign to the Palermo workers could be suggested by the choice of having these elements made by masters from Trapani, who would have resorted to the so-called "Palazzo di Trapani stone".

It was after this experience that Amico himself proposed similar methods for the unrealised project of reinforcement of the dome of St Peter in the Vatican (1743), which at the time was severely dam-aged. This can be seen in the attached report where we read "of such chains I have full experience for having tested them wonderfully in the repair of the great ruins that occurred in the city of Palermo wrought by the earthquake of the year 1726". The drawing, kept in the Vatican Library, shows four masonry 'turrets' around the dome shell and stone chains with 'dovetail' shaped ashlars to compensate for the damage; here, Amico extracts the details to give us a sufficiently clear idea of its conformation (Schlimme 2006, Piazza 2013).

The awareness of the anti-seismic effectiveness of stone chains is subsequently confirmed in other post-earthquake interventions. Gagliardi, whom we mentioned above, summoned Pozzallo in September 1744 to draw up an appraisal on the cracking of the 15th-century Cabrera Tower that was damaged by earthquakes. He proposed insertion of stone chains, to be installed together with iron bars, to reinforce it; it has been suggested that he was probably mindful of the Amico's experience in Palermo after the 1726 earthquake (Nobile 2012, 22).

Use of this technique also following the 1818 earthquake is demonstrated by the report of engineer Fra Bonaventura da Sortino (2 May 1818), who was in charge of assessing the damage and the consequent restorations of the Church of Sant'Agata in Vizzini. To reinforce the vault, in which deep cracks had appeared, the use of "15 stone dovetails, three iron chains to join the bottom of the 'Cappellone' and another four on the sides of the nave" was proposed (ASCt, *Intendenza borbonica*, b. 4212, 1818-19, cc. nn).

2.4 *Supporting walls and pillars*

Another seismic improvement intervention was the construction of supporting walls and pillars, both at the foundation level and on walls above ground, which were aimed at increasing the resistant section of the solid walls, thus avoiding the demolition of considerable portions of the buildings. Walls could be reinforced either through the construction of continuous supporting walls leaning against the external faces or through discontinuous elements, such as pillars connected at the top by arches or architraves.

The construction of supporting walls after the earthquake of 1726 was documented in the convent of Santa Chiara in Palermo where linings in rough-hewn ashlars were made, both on the internal and external facing, in this case made integral with metal bars acting as cross connection (Campisi & Fatta 2009). This technique was mainly used in those cases in which the original masonry belonged to the so-called *pietra e tajo* type, i.e. made up of an internal core of incongruent material, characterised by broken stone, earth, straw and a

little mortar, held by two faces made of roughly-hewn ashlar.

Works to reinforce walls were particularly widespread in the Etna area after the 1818 earthquake. From the documentation, it can be inferred that the effectiveness of the intervention was linked to properly toothing the new masonry to the existing one by means of ashlar blocks which were forcibly inserted by cutting the masonry.

A well-documented case is represented by the consolidation of the Mother Church of Acireale, where Maddem, whom we mentioned above, identified the insufficient dimensioning of the foundations as the main cause for the weak structures (ASCt, *Intendenza Borbonica*, b. 1159, cc. nn). The project considered a consolidation of both the north façade and the south bell tower, which was reinforced at the base with a scarp supporting wall of square basalt blocks (lava stone) called *cannarozzoni*, toothed to the pre-existing masonry (Figure 4).

A similar intervention was also planned for the church of San Giovanni Nepumoceno in Acireale, for which the same architect designed a reinforcement of the foundations with squared-stone supporting walls having a scarp section. This is documented in the report of 15 August 1820 on the restoration of the building (ASCt, Intendenza borbonica, b.1159, cc. nn.).

The use of a scarp profile was also deemed to be effective anti-seismic protection by Baldassare Spampinato, author of a text written at the time of the earthquake that contains observations on the vulnerability of buildings, on the materials used and, on the construction criteria prevailing at that time. The text reads, "If you want solid and lasting works, you have to start from the foundations. What is the form that best suits them? In my opinion, there is none better than the one commonly called scarp; this method must be maintained up to the top of the buildings, as we will say later. The advantage of such a form comes from a principle of mechanics, from which it is deduced that a body is more solid in proportion to the width of the base, on which it rests" (Spampinato 1818, 58).

The construction of supporting walls was also adopted by Antonino Battaglia for the building of the University of Catania, whose north, south and west fronts, after the 1818 earthquake, were evidently out of square. The intervention involved the construction of external faces of variable thickness (from 50 cm at the base to 26 cm at the top) on the three façades, toothed to the walls by means of large semi-square basalt blocks and having foundations 8 m deep (Dato & Magnano di San Lio 1999, 54–55).

Among the seismic improvement interventions adopted after 1818, it is also worth mentioning the use of buttresses (so-called *delfini*), both straight and scarp, as shown, for instance, in the Mother Churches of Zafferana and Tremestieri (Lo Faro & Sammartino 2019), Santa Maria della Catena (Figure 5) and San Giacomo in Acicatena and in the dormitories of the Monastery of SS. Trinità and the Reclusorio della Purità in Catania (Lo Faro, Mondello & Salemi 2018).

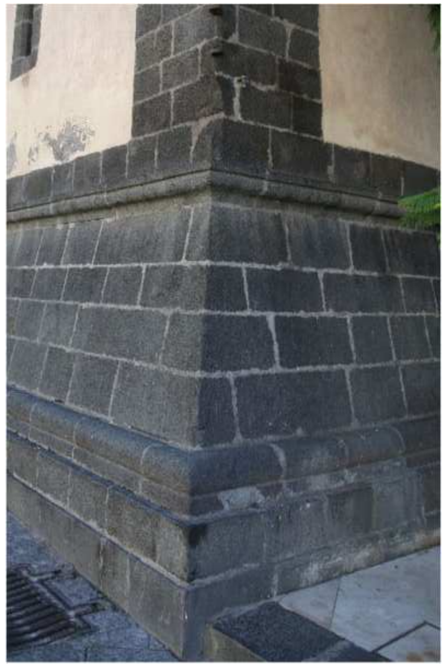

Figure 4. Scarp base with basalt *cannarozzoni* in the south bell tower of the Mother Church of Acireale (photo: L.P. Alfonso).

3 CONCLUSIONS

The comparative study of the construction techniques used after the three earthquakes examined, based on a systematic analysis of memorial sources and archive documentation, supplemented by on-site investigations on some monumental buildings, has highlighted some of the most widely adopted anti-seismic devices in Sicily between the 18th and 19th centuries, while offering a wider panorama of the technical culture of that time.

The study shows that the earthquake of 1726 represented a special chance to reflect on the anti-seismic validity of local construction techniques, and offered the opportunity to implement structural knowledge, to verify the construction choices applied so far, to highlight the critical issues and to make the necessary corrective measures.

The effectiveness of some choices made after the 1726 quake, which were considered to be 'experimental' at that time, entailed significant progress in knowledge, constituting a sure point of reference for the reconstruction works after the subsequent earthquakes that struck the island – in particular the 1818 and 1823 quakes – decreeing their application in both reinforcement interventions and buildings completely reconstructed.

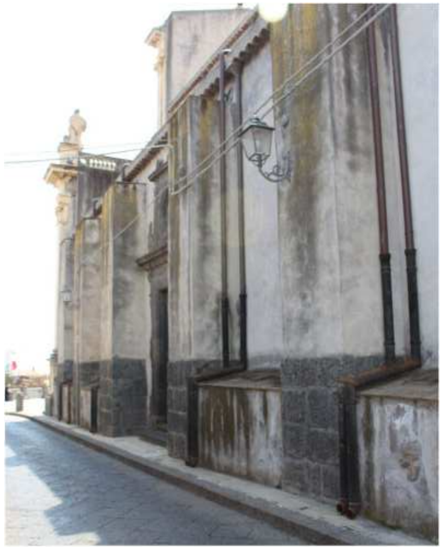

Figure 5. Buttresses placed on the south side of the church of Santa Maria della Catena in Acicatena (photo: A. Lo Faro).

For the 1818 earthquake, there were no particular technical or regulatory innovations, as evidenced by the persistence of already-tested construction solutions. However, some post-earthquake management practices, similar to the current ones, emerged and were then replicated after the 1823 earthquake. As a matter of fact, the verification and monitoring of buildings, and the subsequent reconstruction works, were carried out in a thorough and rigorous manner, as can clearly be seen from the institution by the Intendant of Catania, the Duke of Sammartino, of Commissions for Earthquakes, which were located in the main urban centres of Catania, Bronte, Acireale and Adernò (today Adrano), each of them having competence over a territory. These bodies first carried out a systematic survey of the damaged buildings, leading to the formation of "Charts" that summarised the damage that occurred in each municipality. Each survey detailed the name of the owner, the location, a comprehensive description of the damages observed, the possible "temporary" precautions, i.e. the measures taken in a first emergency phase to avoid further damages, the necessary "shelters" and a first economic assessment of the interventions to be made. In addition, these commissions distributed the funds allocated by the government, approved the restoration project plans for the damaged buildings that each owner had to submit, and supervised the quality of the works carried out in each of the individual buildings (Iachello 2000; Mariotti & Ciuccarelli 2001).

The post-earthquake management system developed after the 1818 earthquake, reflected a renewed administrative system that, as of 1 January 1818, had abolished the island's century-old subdivision into the Mazara, Demone and Noto 'valleys', replacing it with the division into seven Intendencies (Palermo, Catania, Messina, Siracusa, Caltanissetta, Trapani and Agrigento). This system was substantially replicated after the events of 1823.

The cross-reading of these "Charts" and the large number of expert reports drawn up by the engineers and masters involved has provided an instrument of knowledge of the state of the buildings not only in relation to the damage, but also to the techniques used in the consolidation and reconstruction works. The reports have offered a sample of the solutions implemented, based on the adoption of recurrent construction practices, adapted to earthquake prevention criteria.

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