12th INTERNATIONAL CONFERENCE ON STRUCTURAL ANALYSIS OF HISTORICAL CONSTRUCTIONS

SAHC 2021

Online event, 29 Sep - 1 Oct, 2021

P. Roca, L. Pelà and C. Molins (Eds.)

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A publication of:

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

ISBN: 978-84-123222-0-0

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

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THE DAMAGE SURVEY OF CULTURAL BUILT HERITAGE BETWEEN SIMPLIFIED PROCEDURES AND NEEDS FOR IMPLEMENTATION: THE CASE STUDY OF EMILIA-ROMAGNA CEMETERIES

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Keywords: "Emilia 2012" earthquake, Specialised type, Morpho-typological characters, Recurring Collapse Mechanisms

Abstract. *Seven years after the earthquake occurred in Emilia-Romagna, the planning phases related to the cultural heritage reconstruction are coming to a conclusion. At this point, the Agency for reconstruction - earthquake 2012 has launched an unprecedented process aimed at verifying, also through the recognition of the main critical issues, the simplified damage assessment procedures whose application has allowed an aware and sustainable management of the emergency. The Guidelines for the evaluation and reduction of seismic risk on Cultural Heritage, and the Directive 12/12/2013 "Procedures for management of activities for cultural heritage securing and safeguarding in the event of emergencies caused by natural disasters" of MiBAC identify as first cognitive procedure the compilation of sheet to provide vulnerabilities and damage level representation on movable and immovable assets. In particular, they establish two important survey instruments: the A-Church and the B-Palaces sheets.*
These are the only two instruments used between 2012 and 2013 for the damage level characterization of the cultural heritage caused by the "Emilia 2012" earthquake. The widespread use of these sheets has brought to light several problems that have negatively affected the successive economic assessment of the intervention. In fact, if these sheets well describe the vulnerabilities of the specialized types Churches or Palaces, they are ill suited to types with different features, which, in the Emilia-Romagna case, represent about 30% of damage cultural heritage numerically and economically. In particular, the most relevant sample in this set are the cemeteries.
After the analysis of sheets produced for the cemetery type, the need to implementation for the already consolidated procedures has become clear, in order to be able to manage the post-emergency phases on those types that, as cemeteries, represent an important part of the local cultural identity, but that are not addressed in existing tools.

1 INTRODUCTION

Seven years after the earthquake in Emilia in 2012, we have been witnessing an extraordinary response capacity and transformation of the socio-economic system [1]. Now that even the Architectural heritage - the last priority identified - are entering the construction process [2], the key point in the reconstruction phase has been played by the "*invariant factors*" [3], which can be adjusted to other similar disaster areas. The ambitious project promoted by the Emilia-Romagna region, aiming at the capitalization of experiences, is the analysis of what has been achieved so far and the identification of both strong and weak points of the reconstruction process in order to implement the best policies. The project led to the activation of specific research projects [4]. In the field of Cultural Heritage the earthquake made us more aware of the building evolution [5] but at the same time it puts to a test both its structures and its conservative principles [6]. The damage survey is among the first operations to carry out in an emergency phase with the hard task of identifying all buildings requirements (structural, conservative and economic).

In Emilia-Romagna 80% of the damaged public buildings is under protection and the survey campaign has showed some peculiarities in the damage survey report. The significant change in the grants provided for the reconstruction represents a first evidence of this criticality nonetheless it shows the great potentialities in the evolution of the damage survey research started in the Seventies.

One of the most challenging type of buildings is the cemetery, especially from an economic point of view and for a lack of efficacy in the survey tools (Figure 1).

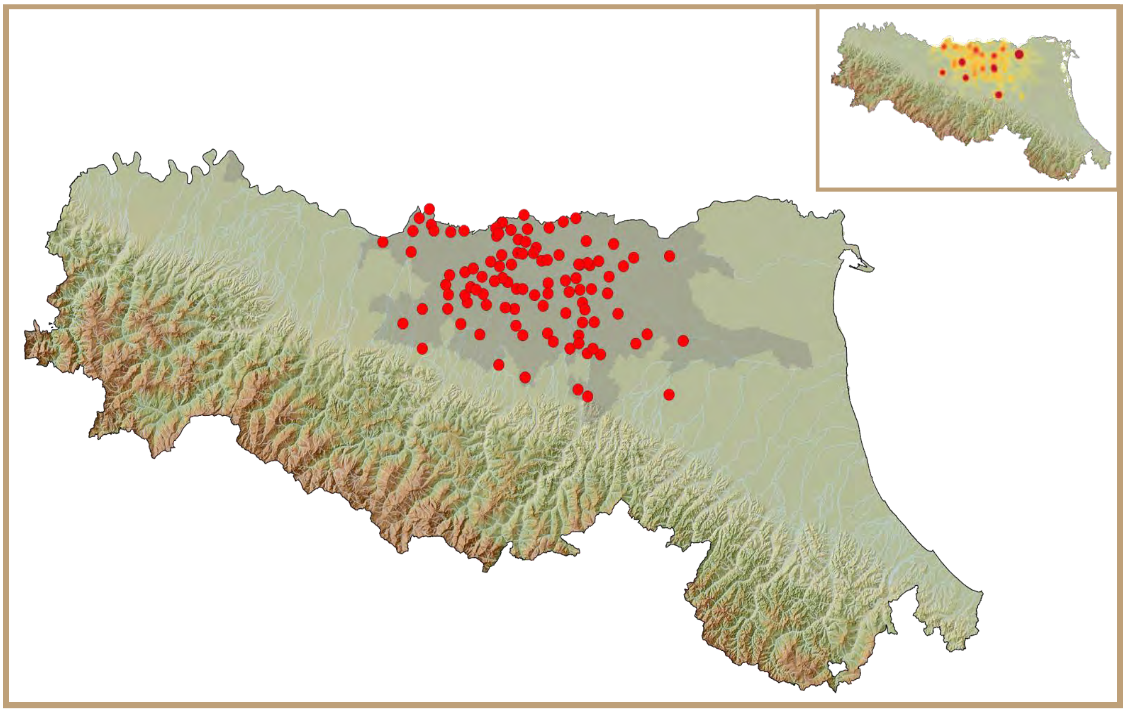

Figure 1: Heatmap of the all Architectural Heritage damaged by the earthquake (top right image) and distribution of the damaged cemetery in the *"crater"* area of Emilia-Romagna.

2 SHEETS TO MEASURE THE DAMAGE SURVEY ON THE ARCHITECTURAL HERITAGE

The earthquakes occurred in the last 30 years have revealed the significant vulnerabilities of architectural heritage. These are strictly related to the building construction quality, the form and dimension of architectural components and anti-seismic devices which are connected to the seismic activity of the area and to the time distance between construction/renovation and the earthquake [7]. A proper identification both of the historic buildings' vulnerabilities and the related activation level of the collapse is a useful tool for prevention and for managing the after-earthquake reconstruction phase. With the aim of providing a support in the complex and delicate emergency management phase, in Italy a series of sheets of different levels have been studied, that through a guided procedure should eventually assess vulnerability, damage [8], practicability and lastly the intervention costs.

The sheets currently in use are the result of several studies and experiences. These range from studies of the research unit coordinated by Doglioni on all churches in the Friuli region damaged by the 1976 earthquake [9] - to whom we owe the decomposition of buildings in macro-elements - to researches carried out by GNDT, INGV and the Department of Engineering of Genova coordinated by Lagomarsino [10,11,12], regarding religious buildings only.

The fact that churches are more vulnerable compared to other historical buildings led in 1987 to a practical application of the first damage survey sheet, the GNDT-S3, which later would become the well-known "FORM A-DC church". This sheet was officially adopted for all religious buildings in 2001 [13], later modified and re-approved in 2006 [14] with a change in the section regarding the collapse mechanisms. More sheets have been added over the years, related both to movable assets and to other *buildings types*. Indeed the protocols for unmovable assets are based on the tendency of *same-type buildings* of being damaged in a similar way regardless of construction age, place, and materials used. Therefore, it was created the "FORM B –DP palaces" [14] for the most relevant historical buildings, which is quite recent and for this reason it is still object of discussion, improvement and optimization. All these sheets were then incorporated by the Italian Ministry of Cultural Heritage in the "*Guidelines for the evaluation and reduction of seismic risk on Cultural Heritage*" [15] and in the Directive 12/12/2013 "*Procedures for management of activities for cultural heritage securing and safeguarding in the event of emergencies caused by natural disasters* which, together with the NTC2018, represent the most relevant legal texts for any intervention on the architectural heritage damaged by earthquakes.

3 THE EMILIA-ROMAGNA CEMETERIES CASE

3.1 Morpho-typological observation on the Emilia-Romagna cemeteries

Modern cemeteries were born in 1804 with the Saint-Cloud edict through which Napoleon Bonaparte regulated the cemeteries construction and definitely demanding to build them far from urban areas. Through the edict, changes already taking place in burial areas were normalised. As a matter of fact, in the 17th century, cemeteries finally gained a topographic autonomy from the church's holy area, opening a debate whether burials should take place inside the church.

Between the second half of the 17th century and the first half of 18th century, public health debates and historical events affected the way people conceive death and especially the concept of "individual" burial (before it was a prerogative of illustrious figures only or for those who could afford it). Indeed through the Saint Cloud edict the individual burial became a "universal" right and since then it has been considered the founding event of the "culte des morts" (cult of the dead) in the modern western culture [16]. Subsequently practices as the "perpetual use" (i.e. the hereditary property of the land) and the funerary monuments became of common use. The modern cemetery, also called by some scholar "cimitero borghese" (bourgeois cemetery) [17], was then defined and seen as a mirror of the society and of a new hierarchical organization.

Furthermore, the decree of 12th June 1804 designated the garden-cemetery as a role model for the cemetery, like for example the Paris Père Lachaise cemetery (France, 1803).

Contrary to basic building, which are strictly connected to the settlement area [18], the *specialised building* such as cemetery does not undergo relevant changes in a *diatopic* sense [19]. Once its features have become solid, they tend to duplicate irrespective of territorial borders. The Père Lachaise model is the first example of the garden-cemetery *typological series* and spread throughout most of Europe and America (e.g. Mount Auburn Cemetery in Boston (USA, 1831).

In Southern Europe, the Saint Cloud edict collided with a still strong medieval tradition: the "*camposanto*" (literally holy field). The pre-existent burial ground integrated new norms and defined a second *typological series*, called by Donghi [20] "*a pianta architettonica*" (architectural drawing series) and by Vovelle "*paysage lapidaire*" (lapidary landscape) [21], in opposition to the garden-cemetery. This is a high architectural value solution, characterized by quadrangular areas fenced by walls, with porticoes of different sizes, which would have later become the most used solution in all small-and-medium-size cemeteries in Italy, especially in the area that we are examining: the Emilia-Romagna Region.

Based on this model, we can identify three different *variants*: a cemetery delimited by porticoes and with a central chapel, a cemetery delimited by porticoes without a central chapel and the reuse and/or renovation of huge buildings outside the city (Figure 2).

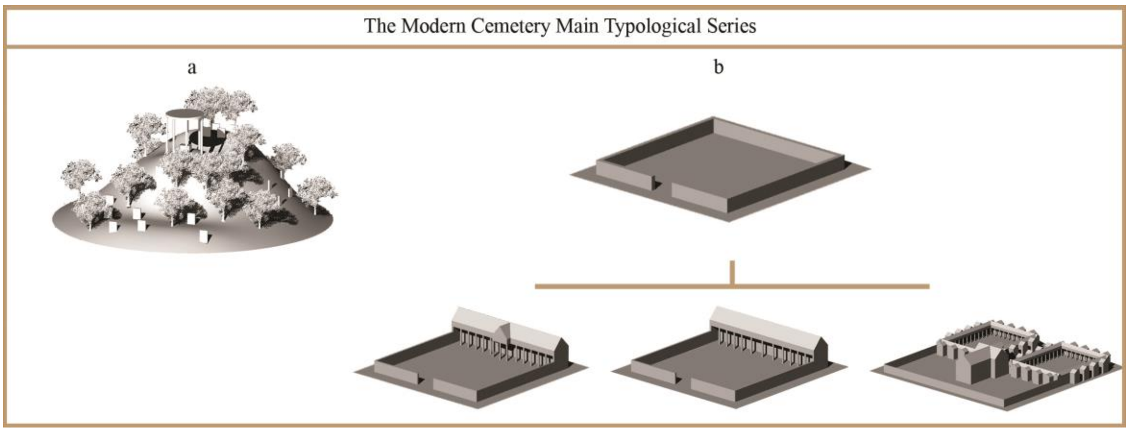

Figure 2: The main *typological series* of modern cemetery. The garden cemetery (a) and the architectural cemetery (b) with its three *variants* presented in Emilia-Romagna

The third group includes two buildings which historically arose on the border of the city: the chartreuses of the cities of Bologna and Ferrara which represent the only cases in Italy of conversion from chartreuse to cemetery [22]. The other *cemetery types* are the most common *variants* in the region, instead. They later have developed in different manners.

The requirements of the enlargement have led to a process that we can find in cities as well. A first growth was made possible through an *infill process* of the enclosure, through the porticoes extension (cemetery of Dosso (FE)), or the combination of family vaults next to each other (cemetery of Vigarano Mainarda (FE)). Alternatively, the cemetery has doubled in the area behind in the cases where an enlargement occurred within a large time distance to last developing phase (cemetery of Finale Emilia (MO)).

Once the space of first enclosure was full, the enlargement has followed the *successive doubling law* [18]. Cemeteries extended more and more and the whole area doubled in volume. Depending on the morphology and on soil availability, the enlargement took place in the area below (cemetery of Bondeno (FE)), or on one side (cemetery of Cento (FE) or Monumental cemetery of Concordia sulla Secchia (MO)). It is worth mentioning also the chartreuses of Ferrara where in the first half of the 19th century the renovation project provided for the creation of a new cloister standing alongside the existent one.

Further observations on cemeteries in Emilia-Romagna can also be made from a constructive point of view. The huge time windows of building development (from the second half of the 19th century – ongoing) coincides in the initial phases with a great transformation of the building process as a result of the introduction of new industrial materials and techniques: reinforced concrete and steel. A first analysis reveals how cemeteries were initially made of long porticoes, often in masonry, that enlarged over time and showed a more frequent use of reinforced concrete. Due to this progressive add-ons and juxtapositions cemeteries are an extremely complicated *building type*, also because traditional technologies exist alongside with new materials like reinforced concrete and steel. At the beginning porticoes are almost always covered by a non-structural bricks vault, usually a barrel vault but still we find several examples of cross vaults as well. The arch then progressively became a depressed-arch and finally turning into a false flat ceiling. Another relevant typological-constructive feature is the presence of columbaria introduced in the Italian cemeteries after the half of the 19th century in order to rationalise space. Indeed it is still possible to find cemeteries (cemetery of Bondeno(FE)) where the “camposanto” model is still a strong reference point. In this case columbaria are absent and the cemetery is a closed arcaded enclosure with headstone set in the floors.

Finally, we should consider the roofing structures. In the first phase they were generally made of wood and they show under two possible aspects: gable roof or single pitch roof reclined outwards. It is interesting to note that the geographical distribution of the two solutions has revealed a tendency in the Ferrara, Reggio Emilia and Bologna’s territories to apply the first solution while in the Modena’s area they preferred the second one. They both include elements as attics and/or decorations aimed at hiding pitches and crowning the entablature above the portico arcade.

In conclusion cemetery is a complex *building type*, where *morphological variants* are combined with a variety of building techniques and materials came up in the next enlargement processes (Figure 3). Both of these aspects are essential features to better understand the structure and the seismic response of an area.

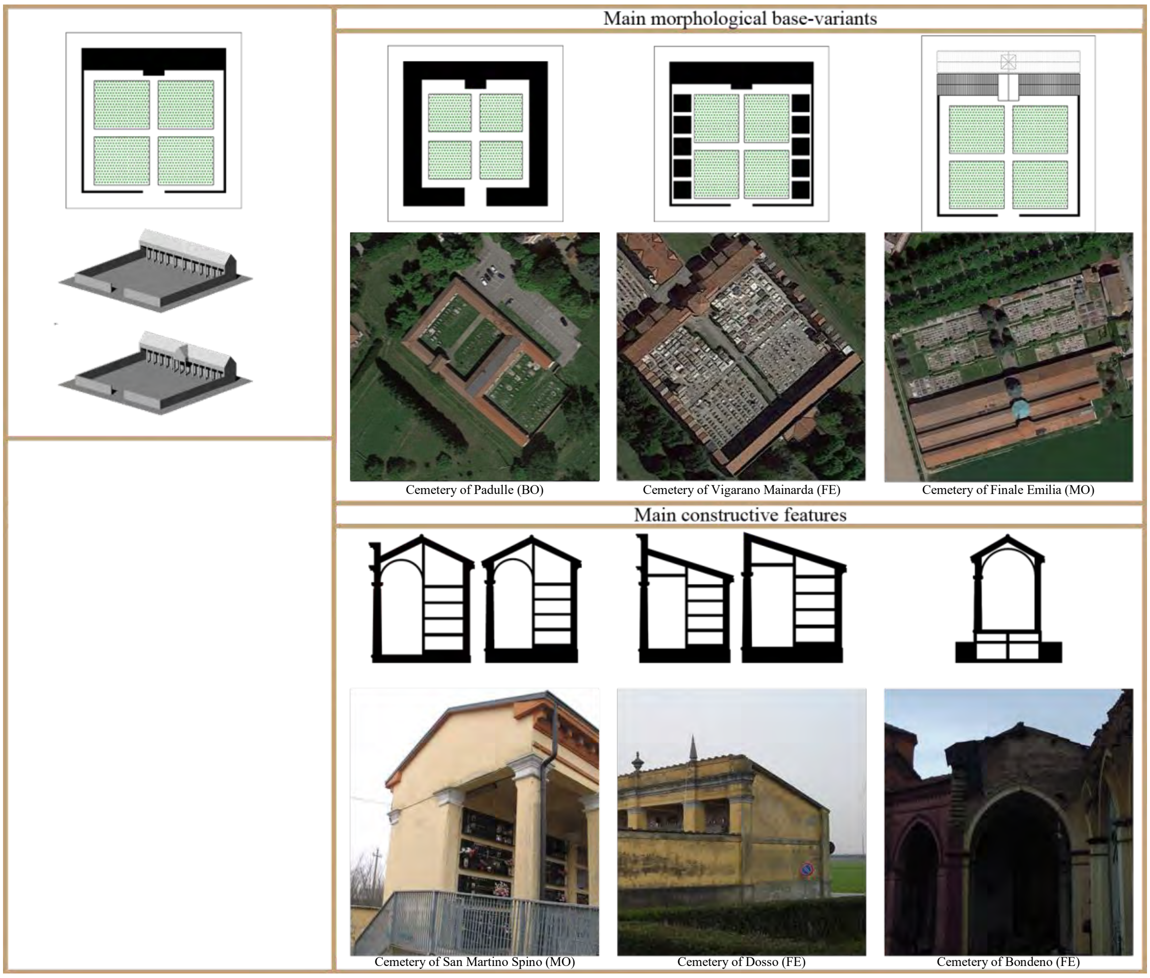

Figure 3: Main morphological and constructive features of the cemeteries in Emilia-Romagna

3.2 Recurring mechanisms of damage shown by cemeteries in Emilia-Romagna

The earthquake in Emilia-Romagna shed light on the vulnerability of historical cemeteries. Out of 300 protected cemeteries in the Region, over 100 were damaged following aftershocks, some of which were affected by major collapses. On average, there are two damaged cemeteries for each municipality in the area hit by the earthquake. Although this is a small percentage when compared to the total architectural heritage affected by the earthquake (more than 1800), issues of a hygienic-sanitary nature, but above all of a socio-cultural nature, require a targeted analysis. As a matter of fact, cemeteries are a place of memories and are an important component in the identity of places that must be safeguarded, especially in earthquake centers.

The analysis of the damage status of cemeteries in Emilia-Romagna allows an initial reflection, which can then be extended on a national scale, concerning the most recurrent collapse mechanisms.

The first evident, typological characteristic that generates an intrinsic vulnerability in the structure is, definitely, the presence of the portico. In this case, it is not a matter of a limited extension within a larger volume, but of a macro-element which, when it is present, covers large areas, often on all sides, extending in length even for several tens of meters. In most cases, moreover, the portico is characterised by arches and vaults that add an additional element of weakness to the structure.

Covering structures are another element of great vulnerability. In both *typological variants*, these are thrust structures which generally have no seismic protection. In this regard, the case of the monumental cemetery of Finale Emilia is relevant. The first core area of the cemetery was built by two porticoed wings, with a single pitch, initially not connected to one another. The project was not brought to immediate completion and it was only from the 1930s onwards that the construction works of the monumental central atrium began. The project for the first expansion dates back from 1945 and the significant modification of the roof, changing it from a single pitch to a double pitch, occurred between 1930 and 1945. From the analysis of the 1945 project, it can be seen that the new roof had tie rods for reducing thrust. Following a survey of the attic of the cemetery, it can be observed that there is no trace of these tie rods and, perhaps, there never was.

It should also be emphasised that, during the expansion phases of the cemeteries, the roofing structure is the element that has undergone the greatest transformation with a marked tendency to replace the wooden structure with a brick-cement structure that is more rigid and heavier, which has entailed an additional burden on the wall structures subjected to seismic action.

The considerations mentioned above are even more evident in light of the collapse mechanisms activated most following the 2012 earthquake:

- Tipping over away from the colonnade floor (Figure 4). It represents the main collapse mechanism of the porticoed wings of the cemeteries, activated for most of the damaged units. This is a result of the summation of the seismic action to that of the thrust roof on the point feature of the portico. Furthermore, the presence of large replaced parts has almost always aggravated the situation, which in some cases led to collapse.

Figure 4: Cemetery of Mirandola - Tipping over away from the colonnade floor. It is worth mentioning the use of reinforced concrete beams and elements in steel in the structures.

- Collapse and/or damage to the vaults and suspended ceilings (Figure 5). Secondary mechanism with respect to that of the portico generally activated for the rotation of the plinths due to the tipping over of the colonnade.

Figure 5: Cemetery of Bondeno (a) and cemetery of Mirabello - damage to the vaults

- Damage by interaction of the structures. The heterogeneous set of buildings that develop by successive additions (see the arms of the columbaria which are completed in the extensions with the preparation of the walls for a new construction) is conducive to triggering interaction mechanisms among the structures (see, for example the interaction between the columbaria and the single central compartment, or when they are inserted in the same building).
- Tipping over of the projecting elements away from the floors (Figure 6). Although it does not trigger a structural collapse mechanism, the presence of attic solutions, point and/or linear architectural elements aimed at hiding the pitches of the roof constitutes a serious vulnerability in the structure. The tipping over of these elements can take place externally or inwards.

Figure 6: Monumental cemetery of Concordia Sulla Secchia -Tipping over of the projecting elements away. In this case the projecting elements are collapsed inside the structures

- Mechanisms of the surrounding wall. The relationship between a modern cemetery and sacred ground is substantiated with the presence of the wall that surrounds the consecrated area. If the saturation of the perimeter has not been completed or if it was carried out for subsequent doubling of the buildings or, also, if the cemetery is saturated by burial in the ground (a typical feature of Israelite cemeteries), the surrounding wall can only represent one of the first vulnerabilities. This manifests itself through the activation of mechanisms of bottom subsidence or tipping over away from the floors.

Finally, the records described here do not deliberately take into account the presence of the single central room, atrium or often chapel, present in almost all the cemeteries. In general, part of the collapse mechanisms reported in "FORM A-DC church" describe the various vulnerabilities that occur under seismic action for these elements.

3.3 The application of existing tools to cemeteries

"FORM A-DC church" and "FORM B –DP palaces" are, therefore, the models applied in the 2012 earthquake in Emilia-Romagna. The use of these tools, strictly connected to the *type* they describe, even if they are the only ones currently available, has highlighted the need to intervene with appropriate adjustments, in particular with reference to *types* of a different nature such as cemetery units. In this case, numerous problems have affected the damage detection process.

First of all, the operators chose the most suitable form to use. The answer to this question in 2012 was ambiguous and followed three different approaches. In some cases, the choice fell on the use of only "FORM A-DC church". This preference, which has the certain advantage of embracing all the aspects borrowed from ecclesiastical buildings (chapels with apses, domes, pediments, etc.), probably arises from the willingness to identify the element of greatest vulnerability in the portico. When filling in the form of the cemetery of Sant'Agostino, both mechanism 5 and 7 are identified as a vulnerability, i.e. 'transversal response of the hall' and 'longitudinal response of the colonnade', so as to be able to insert collapse mechanisms for both actions of the forces acting on the porch. In contrast, the "FORM A-DC church" does not face a problem such as the large spatial articulation of cemeteries, the wings of which can be damaged in different ways.

This is probably the motivation that led most compilers to use "FORM B –DP palaces", a model that, since it is studied for buildings, by means of dividing it into areas it allows greater articulation in the description of the damage, considering the responses of the structure and different mechanisms of collapse for the different parts examined. Although from a first analysis, the form seems to allow greater descriptive freedom, it however lacks the description of the typical mechanisms of large halls of an ecclesiastical nature. The impossibility of indicating the mechanism in the section dedicated to the calculation of the damage index (although it is often correctly reported in the note) prevents the correct calculation of the index itself. Furthermore, it is the same freedom and at the same time the descriptive rigidity of the form that causes excessive simplifications in relation to the extension of the cemetery unit. In the monumental cemetery of Mirandola, with reference to the precise cataloguing of the walls, we finally come to describe the state of collapse of a portion of them but not the initial collapse of the surrounding areas, therefore indicating only one part of the damage.

The inadequacy is even more evident if it is reflected in the damage indices associated with the two cemeteries mentioned above: 0.17 for the Sant'Agostino cemetery and 0.12 for the Mirandola cemetery on a scale from 0 to 1. The first is severely damaged due to the relative movement between the parts generated by the liquefaction of the soil. In addition to collapsed areas, the second cemetery has large portions that are close to collapse. In both cases, the damage index should have been greater than was actually calculated.

Probably, the need to interpolate both characteristics present in the two forms has led to a percentage of compilers for the choice of breaking down the cemetery according to the two models using “FORM A-DC church” for the mortuary chapel and “FORM B –DP palaces” for the remaining areas. Although the choice seems to be the natural solution to the problem of the inadequacy of the single instrument, in reality it does not provide a uniform indication of the damage to the building.

Furthermore, the breakdown of the cemetery into multiple micro-units is an additional problem. The use of multiple forms is in fact allowed in relation to the identification of a structurally separate unit. Although this criterion seems to have been respected for some cemeteries, where the subdivision follows the scan in separate blocks of the columbarium, in other cases the unit is considered as unified giving up the compilation of separate forms for each block and, in others, it is still divided into several parts (for example by construction period), without which they can necessarily be considered structurally independent. In the first case, there is a summary description of the damage. In the second case, there is also a detailed description for each unit that does not necessarily take into account the probable interaction between the different parts.

Figure 7: Different types of family chapels: a) chapels connected at columbaria and at the structures of the cemetery; b) chapels as separated units.

Finally, a further issue found in the damage characterisation process is linked to the experimentation, during 2013, of a “FORM B –DP palaces” aimed at facilitating the compilation of the one adopted to date, which is considered too complex and not very expeditious. The attempt to simplify the new form - which no longer required a detailed description of all the walls, but a twofold rating of the level of damage and on the level of vulnerability - has proved to be particularly complex for compilers as evidenced by a significant amount of forms where the only damage correctly reported is the one related to the roof covering.

In the margin, a necessary reflection is added on whether family chapels are to be considered as annexed bodies (on the same form) or else should they be considered as structurally separate units (a new form)(Figure 7) ? On wall and/or statuary headstones, and on other characteristics related to the *cemeterial type*. It is easy to understand how the tools existing today are insufficient in damage detection operations.

4 CONCLUSIONS

The “2012 Emilia” earthquake has enabled us to identify both the strengths and the weaknesses in the procedures of emergency management useful for the reconstruction.

The damage survey aims at giving a first description useful to understand the damage level of the Architectural Heritage and at improving the safety measures. It also aims at making a first economic assessment of the reconstruction costs, that is why if the evaluation is as close as possible to the real needs we are more aware of the resource management and easily identify priority actions.

Economically, in Emilia-Romagna the *specialised types* not including Churches and Palazzos cost more than 300 million of euros, 59 of which are used for cemeteries. Through a deeper analysis we can see that the costs - intervention by intervention - sometimes end up totally different from what has been previously estimated in the sheets.

The analysis of the buildings damaged by “2012 Emilia” earthquake, belonging to different *specialised types*, currently represents a great opportunity to implement the existent instruments. Such as for previous earthquakes [9,10,11,12], the typological analysis, the vulnerability evaluation, and the observation deriving from the same sheets compiled after the “2012 Emilia” earthquake, would give us new tools to use together with the existent ones.

Acknowledgements. The authors would like to acknowledge the Emila-Romagna Region for funding the research. Funding provided by European Social Fundings of the Operational Programme 2014/2020 Regione Emilia-Romagna: High Competences for Research, for Technology Transfer and Business.

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