ArchiDOCT 17, 9 (2) DATA ii

The Damage Survey Forms for Cultural Heritage Between Simplified Procedures and Needs for Implementation: A Critical Analysis of Data Collected for the Cemetery Type After the "2012 Emilia" Earthquake

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The Guidelines for the evaluation and reduction of seismic risk on Cultural Heritage and the Directive 12/12/2013 of MIC identify as the first cognitive procedure the compilation of specific forms to describe vulnerabilities and damage level on movable and immovable assets after an earthquake. Specifically, they refer to two important survey instruments: the A-DC Church and the B-DP Stately Buildings forms. These are the only two tools 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 forms has brought to light several problems that have negatively affected the successive economic assessment of the intervention.
If these sheets well describe the vulnerabilities of the specialized *types of* Churches or Stately Buildings, they are ill-suited to *types* with different features. In particular, in Emilia-Romagna, one of the most relevant samples of these *types* is the *cemetery type*. Starting from a knowledge of the *cemetery type*, the present paper will analyse the use of these instruments in the cemetery survey to identify the critical points within a damage survey conducted through tools not specifically suited for the *type*. The aim is to deliver a conscious interpretation of the criticality and in the final part define a starting point for a new survey tool.

1. Introduction

The earthquake that struck the Emilia-Romagna Region on May 20 and 29, 2012, severely tested a socio-economic system that alone produced 2% of Italy's GDP. Nine years later, it is clear that this system has had a remarkable resilience, and today only the reconstruction of Cultural Heritage, the last priority set by the Region, is still in the middle of its activities. In fact, in the field of Cultural Heritage, the earthquake made us more aware of the building evolution (Bartolomucci et al., 2012) but at the same time, it puts to a test both its structures and its conservative principles (Dalla Negra, 2012), leading to a longer and more complex reconstruction phase. In this context, 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). This survey aims at leading surveyors to define vulnerabilities and collapse mechanisms (which are the required information for an economic and non-economic damage quantification) starting with the observation of the cracks (the starting date). It is a quick and simplified procedure that, using a "*behavioural approach*" (Baggio et al., 2009), is geared towards obtaining a homogeneous damage indication on a large scale by immediately relating the cracks to the corresponding collapse mechanisms. However, the main critical point is that "...*Simplification generally leads to greater data reliability, as long as the ultimate decision-making* [...] *is well guided*." (Baggio et al., 2009).

In Emilia-Romagna, where almost 80% of the damaged public buildings is under protection, the survey campaign on Cultural Heritage has shown some peculiarities in the damage survey report that negatively affected the subsequent process. During the emergency phases, it has emerged the existence of building *types* that, due to their morphological and typological specificities, do not allow the direct application of the tools and procedures already validated. For these *types*, the respective form A-DC Church

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or FORM B-DP Stately Building, the two forms applied to Cultural Heritage, have proved to be unsuitable to draw a picture of the damage suffered and identify the correct economical assessment. In this framework, one of the most challenging *types* of buildings is the cemetery. Only 34% of the cemeteries in the preliminary phases were economically well estimated using these existing tools.

To illustrate the challenges faced in 2012 by surveyors, the first part of the research paper presents the morphological features of *cemetery type* carried out according to the Saverio Muratori School's interpretation and describes the structure and the peculiarities of the existing tools of damage survey. The second part lists the main problems arising from the use of non-dedicated tools for the cemetery damage survey to demonstrate how it is necessary today to resume studies on damage survey to implement the effectiveness of the tools for Cultural Heritage. In the last chapter, a hypothesis of some data re-interpretation provides a possible solution for the *type* investigated.

2. Interpreting the Cemetery Type

The design of a damage survey tool requires first the awareness of the investigated *type* and its development to define and structurally re-classify its features to allow the surveyors on-site to interpret each building belonging to the *type*. The analysis of the *cemetery type* below, compared to how the current instruments are structured, demonstrate the distance between them and the *cemetery type*, thus justifying the difficulties faced by surveyors between 2012 and 2013 in Emilia-Romagna.

Historically, modern cemeteries were born in 1804 with the Saint-Cloud edict through which Napoleon Bonaparte regulated the cemeteries construction and demanded to build them far from urban areas. Considered the founding event of the "culte des morts" (veneration of the dead) in the modern western culture (Aries, 1977), it is the act through which in France and then in Italy the criteria for planning new cemeteries were definitively established. The modern cemetery was seen as a mirror of society and the new hierarchical organization. Nevertheless, this new attitude toward death did not lead to a new dedicated space but, according to the Saverio Muratori School's interpretation, it changed the features of the pre-existing cemeteries, emphasizing some peculiarities and determining the definition of two typological series connected to different matrices of specialization (Maffei & Maffei, 2011).

Through the ban of the stacked burial in the mass graves and the establishment of the practice of the singular burial as mandatory, sometimes combined with the incineration as well (Ragon, 1986), still the new rules of the edict demanded a rethinking of the model for burials.

On one hand, we see the definition of garden-cemetery. In this case, the matrix of specialization is a naturalistic one and it comes from the medieval cemetery built outside the city and settled in the twelfth century. Characterized by a wide but enclosed perimeter, the abundance of space makes family chapels and great singular tombs the primary and preferred method of burial here.

On the other hand, especially in southern Europe, the Saint Cloud edict collided with a still strong medieval tradition, the "Camposanto" (literally "holy field"), a cemetery with large porticoed wings where bones of exhumed bodies were drained before placing them in the ossuaries above. The new cemetery codes were incorporated into this pre-existing cemetery model defining a second typological series called by Donghi (Donghi, 1935) "a pianta architettonica" (architectural drawing). It adapts its pre-existing architectural features to the new regulatory requirements by reintroducing an archaic burial model that allowed responding to the new needs of singularity and recognisability, while also maximizing the use of space: the columbarium. This is a high architectural value solution, characterized by quadrangular areas fenced by walls, with porticoes of different sizes, in which are placed the new burials. It is 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 it we identify three different variants: a cemetery delimited by porticoes with a central chapel, a cemetery delimited by porticoes without a central chapel and the reuse of huge buildings outside the city. These variants later have developed in different manners. A first growth was made possible through an infill process of the enclosure, through the porticos' extension, or the combination of family vaults next to each other. Alternatively, the cemetery has doubled in the area behind. Once the space of the first enclosure was full, the enlargement has followed the successive doubling law (Caniggia & Maffei, 1987). Cemeteries extended more and more and the whole area doubled in volume.

Further observations on Emilia-Romagna cemeteries 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) coincide 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 more frequent use of reinforced concrete. Due to these progressive add-ons and juxtapositions, cemeteries are an extremely complicated *building type*, also because traditional technologies exist alongside new materials like reinforced concrete and steel.

In conclusion, a cemetery is a complex *building type*, where *morphological variants* and developments are combined with a variety of building techniques. The outcome from a structural point of view is a structure with some peculiar vulnerabilities such as the porticoes or projection elements tipping over, the damage to the vaults and suspended ceilings, the damage to surrounding walls etc...

3. Forms for the Damage Survey on Architectural Heritage

3.1. History and Principle of Damage Survey Forms for Cultural Heritage

The earthquakes that 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 (Lagomarsino & Podestà, 2005). A proper identification both of historic buildings' vulnerabilities and related activation levels of collapse is a useful tool for prevention and for managing the after-earthquake reconstruction phase. To provide support in the complex and delicate emergency management phase, in Italy a series of forms of different levels have been studied, that through a guided procedure should eventually assess vulnerability, damage (Papa & Di Pasquale, 2013), practicability and lastly the intervention costs.

The forms 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 (Doglioni et al., 1994) to researches carried out by GNDT, INGV and the Department of Engineering of Genova coordinated by Lagomarsino (Lagomarsino & Podestà, 2004a, 2004b, 2004c), regarding religious buildings first, and then enlarged to several *buildings type* (D'Ayala & Spence, 1995; Mouroux & Le Brun, 2006).

The fact that churches are more vulnerable compared to other historical buildings led in 1987 to a practical application of the first damage survey form, the GNDT-S3, which later would become the well-known "FORM A-DC church". This form was officially adopted for all religious buildings in 2001 (Presidenza del Consiglio dei Ministri, 2001), later modified and re-approved in 2006 (Presidenza del Consiglio dei Ministri, 2006). More forms have been added over the years, related both to movable assets and to other *buildings types*. Therefore, it was created the "FORM B –DP Stately Building" for the most relevant historical buildings, which is quite recent and for this reason, it is still the object of discussion, improvement and optimization.

The theoretical framework from which the damage survey tools arise is based on the idea that analogous structural elements tend to suffer similar damage regardless of the time of construction and the used materials, factors that may increase or decrease the level of vulnerability but not eliminate the vulnerability itself (behavioural approach). Assuming this, the instruments have been designed by the observation of the real recurrent damage that occurred on structures belonging to the same typology. The damage was mapped, interpreted and embedded in specific abacuses which, according to the *building type*, illustrate how the structural problems appear in the buildings through the use of a simplified scheme that exemplifies how cracks are located about collapse mechanisms. These schemes represent a synthesis of structural behaviours related to macro-elements (Doglioni et al., 1994) into which a building can be divided. Since structural behaviour in the case of an earthquake has a limited number of possibilities, the core of a suitable Cultural Heritage damage assessment is then represented by how effective are these abacuses in respect to the building investigated. In fact, since the forms in the Cultural Heritage field are used by professionals coming from different areas, such as art historians, archaeologists and architects, these abacuses must guide the surveyors to select only the cracks that they can include within these simplified schemes.

3.2. Structure and content of current damage survey forms for Cultural Heritage

The form A-DC Church (hereafter A-DC form) has been studied since the 1976 earthquake specifically for churches, and in its final design, it includes an of list 28 collapse mechanisms related to macro-elements such as the façade, the nave, the aisles, the apse, the chapels and the tower bell, typical churches architectural features.

The form is divided into two sections. The first aims at locating the property, and identifying all pieces of art. The second one assesses the conservative state, the damage index, the practicability and the repair costs. In particular, the damage index is calculated by taking into account all possible collapse mechanisms that may be activated among the 28 present (it determines the parameter "n") and the level of damage associated with each of them (it determines the parameter "d"). The damage index, Id= d/5n, is then obtained by the ratio of the two factors collected. It is worth mentioning that "n" is represented by the sum of all possible mechanisms, regardless of how many times a macro element is used. The presence, as an example, of three or five aisles is therefore irrelevant for the index calculation. Finally, to calculate "n", each collapse mechanism associated with a macro-element must be considered as vulnerable just because the macro-element is in the church.

FORM B-DP Stately Building (hereafter B-DP form) is divided into two sections as A-DC form but, if the first section is almost alike, the second section is set up differently. Although it aims at collecting the same type of data of the A-DC form, the B-DP form has more generic and smaller macro-elements as well as external walls, inner walls, floors, stairs, porches, etc...

In this case, before identifying the activated collapse mechanisms, surveyors are required to provide a long and detailed description of materials, dimensions, and damage state of each component. Once this survey is being meticulously carried out, it would be possible to identify collapse mechanisms, their activation level, and calculate the damage index, but even if the damage index formula is the same, the identification of parameters for calculation ("n" and "d") is quite different from A-DC form. In fact, for "n" identification must be considered only the total number of macro-elements and not their possible structural behaviour during an earthquake.

An additional difference in the index calculation is the introduction of the "secondary" mechanisms concept in the section of damage identification. This integration in B-DP form is related to the complexity of stately buildings which are generally multi-storey buildings. In some macro-element, we can observe different mechanisms on some floors with their related damage levels. In order not to overestimate the damage level in a component, the code "secondary" should therefore be attributed to all collapse mechanisms with the lowest damaging effect in the same macro-element. The code indicates that the damage level should not be counted in the "d" calculation. This means that each macro-element should be considered only the collapse mechanism with the highest damage value.

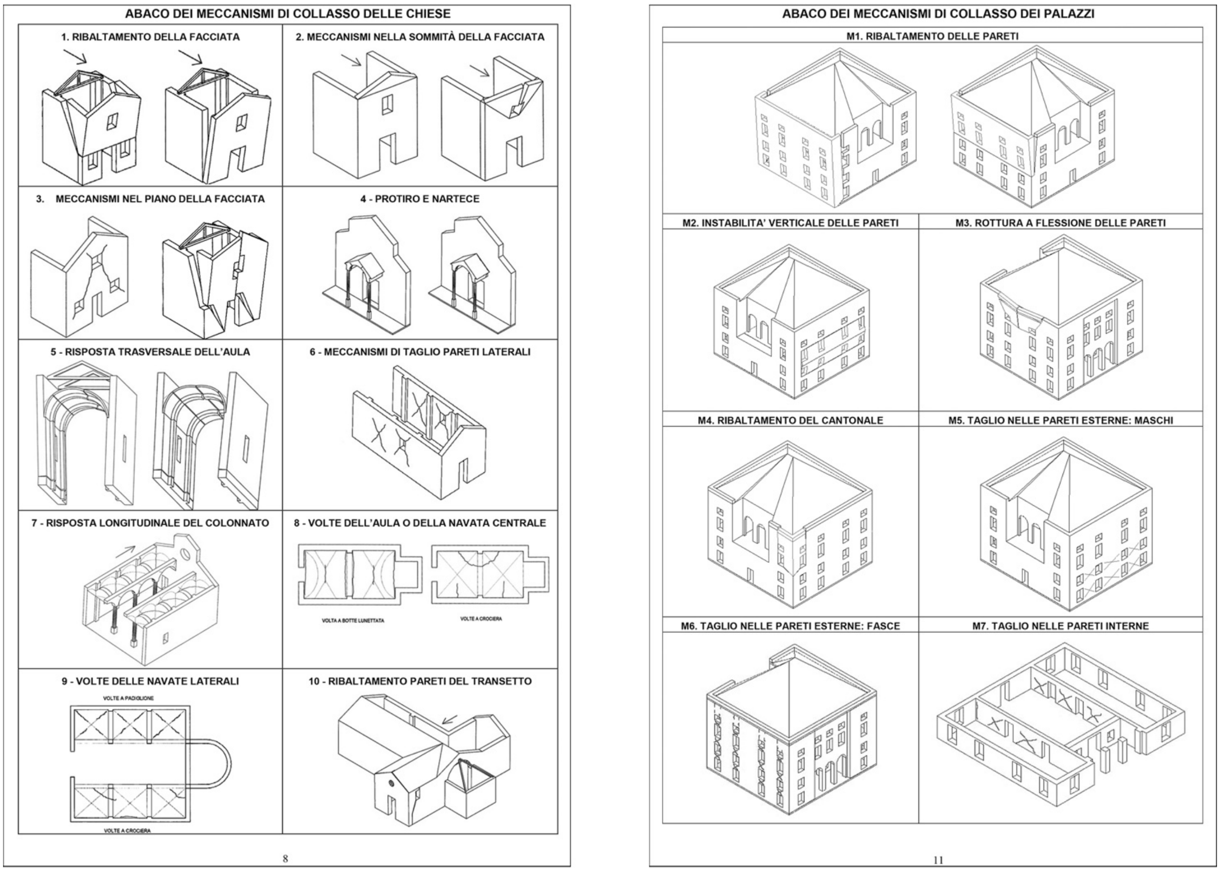

Figure 1. Extract from collapse mechanisms lists for churches and stately buildings attached to the respective forms.

Source: A-DC and B-DP forms

4. Analysis of Cemetery Damage Survey Forms Fulfilled in Emilia-Romagna

Even though A-DC and B-DP forms are very different in the damage is represented and identified, as shown in Fig. 1, still, these were the only two tools through which cemeteries were surveyed between 2012 and 2013. The first form is closely linked to the architectural and functional aspects of churches, the second one is open to different spatial configurations as long as they can all be investigated. 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 concerning *types* of different nature such as cemeteries. Neither of these instruments after the analysis of their application appeared completely suited to the damage survey for *cemetery type*. The analysis was carried out through the identification and comparison of the following parameters relating to the forms filled in:

- type and number of forms filled out per cemetery
- correspondence between described and observed damage
- formal accuracy of the damage index

presence of ambiguous fields and comparison of relative solutions to perform the analysis according to the parameters, the corresponding abacus of the recurrent collapse mechanisms for the i*nvestigated type* was preliminarily created (Fig. 2). This is based on the morphological analysis previously described for the identification of macro-elements and on the structural analysis of the actual recurrent damage observed, based on Giuffrè (Giuffrè, 1991) historical construction interpretation, through the use of the photographic data which accompany each inspection carried out between 2012 and 2013.

The results of this analysis highlighted the following problems that affected the damage survey process:

- Criticalities related to tool choice. First of all, the operators' problem was the choice of 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 the A-DC form. 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. In contrast, this form does not face a problem such as the large spatial articulation of cemeteries, the wings of which can be damaged in different ways. Probably, for this reason, most compilers decided to use the B-DP form. It is a model that, since it is studied for buildings, employing dividing it into areas, allows greater articulation in damage description, considering the responses of the structure and different

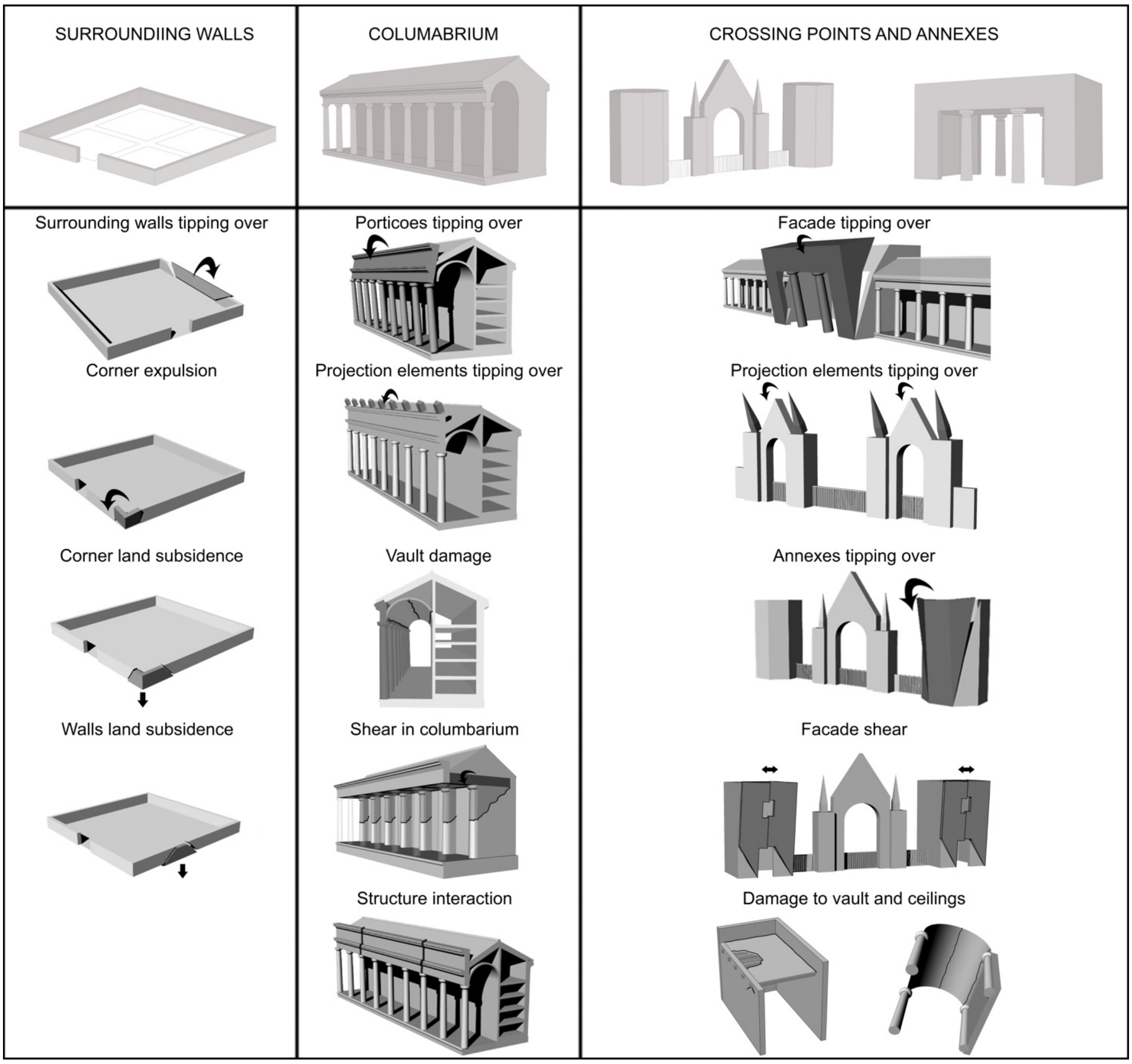

Figure 2. Extract of abacus created for *cemetery type*.

Source: own elaboration

collapse mechanisms for the different parts.
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 prevents the correct calculation of the index itself.
Probably, the need to combine some elements of the two forms pushed a certain number of compilers to break down the cemetery into two models, using the A-DC form for the mortuary chapel and B-DP form for the remaining areas. Although the choice seems to be the natural solution to the problem of the inadequacy of a single instrument it does not provide a uniform indication of the damage to the building.

- Criticalities related to macro-elements identification. The identification of the macro-elements is the core of the damage survey. Their subdivision and diagrams according to recurrent behaviours patterns are guidelines followed by the surveyors to identify which collapse mechanisms have been activated after the earthquake. Although the 28 mechanisms in the A-DC form and the 22 in B-DP form well describe the *types* for which they have been created, once applied to other *types* they generated considerable uncertainty.
Once the surveyors chose a specific tool, their approach to *cemetery type* followed different paths by associating the architectural features of cemeteries with some macro-elements in the forms. For example, in D-BP form, an M18 mechanism, "damage to projecting elements", is used to describe damage to gables or attics even if in the diagrams it refers to dormers and balconies. In other cases, instead, they added in D-BP form completely new elements and/or additional macro-elements from the A-DC form. As a result, M23 and M24 appear in the list, making it possible to identify any damage to apses, gables and surrounding walls. In many cases, not knowing which collapse mechanisms to refer to, has led surveyors to report minor damage in the note, not including it in the damage index.
We should also consider that cemetery structures are not easily accessible. We refer here to the columbaria

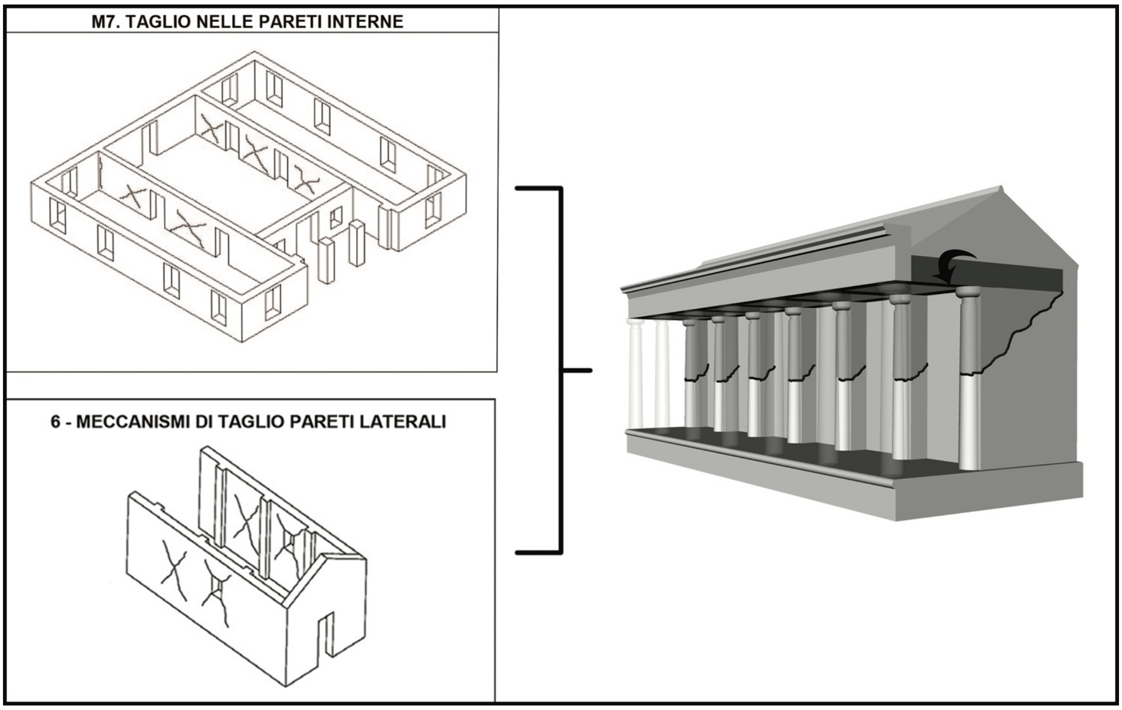

Figure 3. Difference between how shear is diagrammed in the abacuses for Churches and Stately buildings and how this could be schematized for cemeteries.

Source: own elaboration

cross walls, where the only part we can see is the thickness between burial niches. We can survey the columbaria cross walls as macro-element inner walls of the B-DP form, but we cannot recognise any damage by using schemes of pre-existing forms (Fig. 3). The diagrams let us understand the structural behaviour by observing the cracks mainly from a frontal wall view or, in challenging cases, by observing them from other sides. Since it is impossible to recognise the damage by solely observing the wall thickness the macro-element has often been neglected.

As a result, we collected a set of unreliable and inconsistent data. Since there are no clear and univocal guidelines, a correct survey depends first on the operator's ability to summarise the behavioural cemetery features without necessarily having any previous knowledge, and then on relating them to the existing tools.

- Criticalities related to damage index calculation. The identification of the damage index is one of the final aims of the damage survey. In addition to providing an overview of the damage, the index should also identify a parametric cost to be multiplied by the building area.

  With the same index formula, Id= d/5n, the parameters "d" and "n" are counted differently in the two forms, but in both the expected result is a number on a scale from 0 to 1, where 0 means lack of damage and 1 the almost totally building collapse (Grüntal, 1998). The difference in calculation has been leading to many mistakes. If the setting of the A-DC form (collapse mechanism on the macro element: activatable YES/NO + damage level from 0 to 5) hardly leads to an incorrect compilation, the situation is different for the B-DP form. On one hand, being familiar with the older A-DC form has been leading surveyors to use the same calculation while dealing with the same formula, on the other hand, the length and the fragmentary organisation of the data have been generating a few miscalculations. The most common mistake in the "d" calculation is the not-attribution of the "secondary" parameter, overestimating the damage.

  For what concern the "n" parameter thought, we can find several errors, ranging from the not-counting of the pre-marked parts to the incorrect counting of macro-elements (indication of several macro-elements different from those detected in the previous section). Common mistakes are also the non-multiplication of macro-elements inner walls (indicated in the form) and, in the worst case, the multiplication of the macro-elements by the collapse mechanisms that have been activated, seriously underestimating the index. The result is damage indices which are in some cases only slightly different from the correct ones but in other cases are even greater than 1, a meaningless result.
- Criticalities related to experimental form introduction. A further issue in the damage characterization process is linked to the experimentation, during 2013, of a new B form 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 vulnera-

bility - has proved to be particularly complex for compilers. A large number of forms were not filled in the damage section, often preferring a detailed description of the damage in the notes.

Furthermore, the analysis of collapse mechanisms identified by the two forms, at first sight, seemed to display a different tendency in the *cemetery type* collapsing.

The damage survey carried out in 2012 with the B-DP form shows a prevalence of M9 damage mechanism, while, although still present, this predominance decreased significantly in the 2013 survey using the experimental form. Conversely, mechanisms from M10 to M13, which were hardly identified in 2012, appeared to be increasing.

This, however, is not related to the activation of different collapse mechanisms in cemeteries, but it shows how much the design of these forms influences the surveyors' choices and how the use of unsuitable tools can lead them in completely different directions.

Between the B-DP form and its simplified version, there has been a change in terminology that drastically changed the survey. The adopted form identifies mechanism M9 as damage to porticos and loggias. This definition seems to include both in-plan and out-of-plan mechanisms. Moreover, the scheme associated with this damage displays squashing cracks in columns, cracks in the longitudinal direction of arches and cracks in the vaults. Therefore, it has led to a strong reduction in the identification of other mechanisms which were considered already included in M9. In the 2013 simplified form, the same M9 mechanism was defined as damage of slender elements by compression, associating the damage to columns crushing only. This definition increased the identification of collapse mechanisms related to vaults and floors (from M10 to M13).

Finally, it is worth noting that both the recognition of vulnerabilities due to constructive (M19) and shape (M20) irregularities and the preference to consider surrounding walls as a new macro-element were increasing. We could explain the variation above by analysing a further parameter: the surveyors. In 2012, twenty-seven people carried out the survey filling in an average of two forms each. In 2013, there were only seven surveyors instead. Four out of seven surveyors completed no more than 2 forms each, while the remaining three carried out most of the survey. In the second case, the surveyors gained more knowledge about *cemetery type* by visiting a larger number of cemetery buildings. Consequently, the surveyors improved their abilities in the identification of vulnerabilities and damage that they had understood to be recurring, such as damage to surrounding walls or M19 and M20.

5. Conclusion and Possible Development

After the analysis, it is possible to state that the morphological and structural distance between some *building's types,* such as cemetery, and the existing damage survey instruments, not specifically designed for them, is the cause of incorrect damage survey. Since it was not possible to calculate a univocal and right damage index, it was also difficult to properly describe the damage state of Cultural Heritage and identify a correct parametric cost, affecting the subsequent reconstruction phase.

Additionally, the mistakes in the application of the damage index formula, which is mathematically simple, claims the need to provide greater and adequate training for the surveyors who are now cyclically called upon to carry out the damage survey. 20 years after the introduction of the forms in the Italian legal system, a lack of training of the operators can no longer be accepted.

A further conclusion can be drawn from the failure of the experimental B form. It demonstrates how the design of such as these tools is a long-term process whose success is achieved by mediating between the needs of quickness and the needs of data accuracy, and therefore it is necessary today to persist in the studies to improve the B-DP form or to create a new one. In addition, it also illustrates how a little change in an ambiguous parameter can transform the survey outcomes.

However, if on one hand, the analysis of damage forms applied to cemeteries in the 2012 earthquake highlights the criticality of their application to the *type*, on the other hand, it offered us an opportunity to improve the effectiveness of existing tools by introducing new ones. The data and the analyses already collected can be re-organized and systematized to acquire useful information for the development of a new tool for the *cemetery type*.

To compare the forms produced, it was necessary to perform a morphological and damage status analysis of the cemeteries to create an abacus of recurrent mechanisms based on the actual damage of the investigation set. This is the first step for the implementation of a new damage form for *cemetery type* as it provides an exemplification of the recurrent behaviours. The identification of the most suitable design for the data acquisition based on these schemes is the next step to complete for configuring a new tool calibrated on the complexity of the cemeteries.

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