RISK MANAGEMENT POTENTIAL OF TECHNICAL DATA INVENTORIES ON BUILT CULTURAL HERITAGE: A CASE STUDY FOR THE CHURCHES OF THE PORTUGUESE ROUTE OF THE ROMANESQUE

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ABSTRACT:

The proposed paper discusses the importance of having adequate data inventories about the technical characteristics of built cultural heritage properties for the management of both extensive and intensive risks. As a case study, the paper presents the Property Identification Form (IDI Form) developed to compile and organize the technical information collected from surveys carried out in the churches of the Portuguese Route of the Romanesque (RR). The information collected from each property by the IDI Form involves geometric data, structural characteristics, data on the construction processes, the state of conservation and existing damage, reference to interventions carried out over time, and data on the interaction of the property with its surroundings. The IDI Form establishes an important contribution to organize such technical data in a common format, enabling its statistical analysis for risk management purposes. The IDI Form was used in the survey of the 44 churches of the RR and outcomes of some statistical analyses of the data that were performed are presented herein to illustrate their potential for cultural heritage risk management.

1. INTRODUCTION

Multiple efforts are increasingly being made to improve disaster risk reduction capacity worldwide driven by international frameworks such as the Sendai Framework for Disaster Risk Reduction 2015-2030 or the International Risk Governance Council Risk Governance Framework. These and other frameworks recognize the importance of cultural heritage and its irreplaceable value for society. Still, safeguarding cultural heritage implies the need to act on both the prevention and preparedness sides of the disaster management cycle, as well as the need to develop risk management strategies that cover both “everyday” (extensive) and severe (intensive) risks. Extensive risks have not yet received sufficient and explicit attention from the various international frameworks, mainly because they are often unreported. However, evidence suggest that a large proportion of cultural heritage damage and losses is caused by everyday extensive risks.

The availability of relevant data is essential to develop effective risk and disaster management strategies. For the particular case of preserving built cultural heritage properties, the availability of inventories with technical characteristics (e.g. geometric surveys, data on the construction techniques or material properties) is fundamental for managing both extensive and intensive risks. Moreover, efficient management strategies also require the surveyed data to be organized in a standardized format so that risk assessment and mitigation can be performed in a more systematic and effective way. This standardization feature of the data is particularly relevant for managing sets of heritage properties with similar construction processes and architectural characteristics.

In this context, the proposed paper presents the development of a standard Property Identification Form (termed the IDI Form) for the systematic collection of relevant technical data about a specific type of cultural heritage property. The IDI Form presented herein was developed for churches of the Portuguese Romanesque period and was used to collect data for the 44 churches of the Portuguese Route of the Romanesque (RR) (RR, 2017). For each church, the IDI Form allows the recording of its geometric characteristics, structural typology, construction process(es), level of damage, changes and works carried out over time, the existence of heritage assets attached to the building, and its interaction with the surrounding environment. The collected data sets the basis for a technical database and a comprehensive cultural heritage property management tool. The proposed paper discusses the main characteristics of the IDI Form and presents some results obtained from the statistical treatment of the data recorded by the survey of the 44 churches to illustrate the potential of this data for risk management.

2. THE IDI FORM

Data collection forms are developed to support and enhance the efficiency of inspection and diagnosis procedures over time. By providing a systematic organization system for the relevant data of heritage properties, they facilitate data updating over time as well as analysing data variations by comparing parameters recorded at different times using the same format. In general terms, this type of form should be able to characterize the overall geometry of the property, the construction solutions that were adopted, the state of conservation of the property and its surrounding environment, among other aspects.

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The IDI Form presented herein was specifically developed for the RR to establish a tool providing a systematic organization of technical data. Given the numerous inspections and works carried out in the RR properties by several institutions over time, e.g. see (Costa et al., 2012a; Costa et al., 2012b; Costa et al., 2012c; Arêde and Paupério (2014); Arêde et al., (2015)), the data gathered by the IDI Form will form a database with the evolution of several properties of the buildings and the history of the works that were performed. In this context, the IDI Form for churches of the RR was developed to compile all the relevant technical data for this type of construction in a single form. The systematic and uniform inventory of all the technical data that are relevant for these heritage properties has several advantages for their risk management and represents a central tool to support decision-making. For example, a careful statistical analysis of that data can help to identify links between heritage properties that can be used to optimize risk mitigation strategies.

The IDI Form was developed in digital format so that it could be filled using any device capable of reading Adobe Acrobat documents (i.e. PDF). Among other things, this facilitates exporting the collected data (which is done automatically) and the possible extension of the form if more fields are required in the future. The current version of the IDI Form collects data on general parameters such as the type of roofs and ceilings of the chancel and of the main chapels, or if there are decorative cultural heritage assets attached to the walls or ceilings, as well as data on more technical parameters such as wall slenderness indexes or if wall corners are built with interlocking masonry. The form also records specific data that can be used to perform a risk assessment for different intensive or extensive hazards.

The IDI Form is divided into 8 main sections that are: Identification of the property; Geometric characterization of the property and walls; Classification of the masonry walls of the property; Other construction elements of the property; Relation of other elements with the property; Interaction of the property with the surroundings; Evaluation of the general state of conservation and damage records; Identification of structural macro-elements. To illustrate the format and organization of the form, Figures 1, 2 and 3 present parts of the form corresponding to part of the geometric characterization of the property, to part of the classification of the walls of the property and to the building interaction with the surrounding environment.

B. GEOMETRIC DATA:

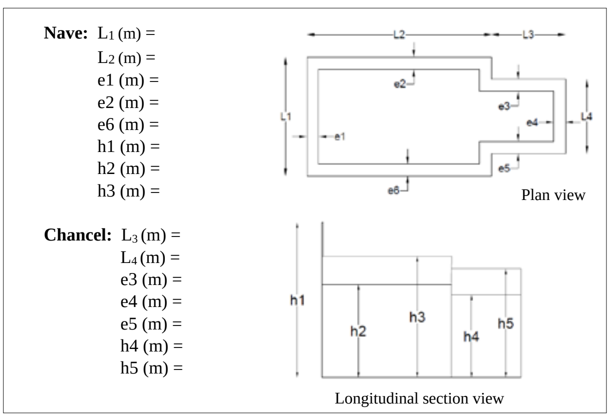

Figure 1. IDI Form: part of the geometric survey section.

C. CLASSIFICATION OF THE CHURCH MASONRY WALLS

Main façade:

h (m):________ e_1 (m):________
Slenderness ratio (h/e_1):____________
Percentage of opening areas:__________

Type of masonry: ☐ Homogeneous of class:
☐ Heterogeneous of classes:
Material: ☐ Granite ☐ Schist ☐ Brick
☐ Limestone ☐ Other

Wall has transversal connectors: ☐ No ☐ Yes ☐ Less than 3 per m^2
☐ Between 3 to 4 per m^2
☐ Between 5 to 6 per m^2

Wall leaves: ☐ One ☐ Two ☐ Three ☐ Not identified

Type of joints: ☐ Irregular ☐ Aligned irregular joints
☐ Aligned regular joints

Type of corner quoining: ☐ Global ☐ Partial ☐ No quoining
☐ Impossible to see the interior

Stone dressing: ☐ Good ☐ Adequate ☐ Bad

Regularity index: (1)

There is: ☐ Exterior plaster ☐ Interior plaster

Figure 2. IDI Form: part of the masonry wall classification section.

F. INTERACTION WITH THE SURROUNDING ENVIRONMENT:

Type of building: ☐ Isolated ☐ In a row (in the middle) ☐ In a row (in the end) ☐ Corner
☐ Urban construction ☐ Rural construction

Proximity of combusting/flammable materials: ☐ Yes ☐ No

Slope of the terrain: ☐ Flat ☐ Gentle slope (<5%) ☐ Significant slope (> 5%)
☐ Terrace ☐ Without a retaining wall
☐ With a retaining wall ☐ In good condition
☐ In bad condition

☐ Good ☐ Average ☐ Bad
Presence of water drainage system around the church: ☐ No ☐ Yes
Drainage system for rain water: ☐ No ☐ Yes
Proximity of river flows: ☐ No ☐ Yes: Possibility of flooding: ☐ Yes ☐ No

Figure 3. IDI Form: part of the survey regarding the building interaction with the surrounding environment.

3. DATA COLLECTED FROM THE CHURCHES OF THE RR USING THE IDI FORM

To illustrate the potential of the data recorded by the IDI Form, some results of the analyses performed using the data collected during the technical surveys to the 44 RR churches are presented in the following. The presented results focus on the analysis of parameters that are relevant to aspects both related to intensive and extensive risk assessment and mitigation.

Prior to this data analysis, a brief overview of the RR is also presented, focussing on its objectives and on the type of monuments that are included in the RR.

3.1 The Portuguese Route of the Romanesque

The RR is a cultural route of the northern region of Portugal that promotes the integrated and sustainable development of the region, as well as territorial competitiveness, cohesion and identity. It involves 58 Romanesque-style monuments located in an area that includes 12 municipalities (Figure 4). The RR was created to harness the cultural potential of the region and promote its sustainable development. The cornerstone elements which support the RR are the conservation and enhancement of the economic values of the Romanesque-style monuments and the valuable intangible heritage of that region, such as the traditions, the gastronomy and the arts and crafts. The preservation and promotion of this legacy governed the development of the RR to achieve its broader mission: to drive the development and the sustainable socio-economic growth of the region. Such ultimate goal relies on establishing and promoting an attractive and high-quality touristic framework that would be a reference destination in the national and international fields of cultural and landscape touring.

Figure 4. Location of the RR.

This Romanesque architectural heritage is closely connected to the founding of the Portuguese nation and dates as far back as the 11th century. Due to the evolution of the socio-economical characteristics of that region over the centuries and to the lack of adequate conservation and use, many of these constructions became extremely degraded. Nevertheless, the local population still had a strong emotional connection with that heritage and was seeking to be involved in their recovery and reuse to foster regional growth. Therefore, when the project began in 2000, the active engagement of the local population in the project was seen as an essential factor for success to be achieved. In general terms, the objectives of the RR are (RR, 2017): to promote land-use planning by valuing the Romanesque-style cultural and architectural heritage; to create a new productive sector capable of generating wealth; to contribute to the change of the internal and external image of the region; to promote capacity building of the human resources of the region; to contribute to the development of qualified employment.

The cultural heritage properties that integrate the RR belong to the several municipalities and have different typologies such as churches, monasteries, bridges, towers or funerary monuments, among others (Figure 5).

Figure 5. Examples of cultural heritage properties from the RR.

Most of the properties that integrate the RR are religious heritage constructions and churches are the most common property (there are 44 churches, isolated or part of monasteries). To illustrate the type of churches of the RR, the Church of São Mamede of Vila Verde and the Church of the Monastery of São Pedro de Ferreira are shown in Figure 6. The figure displays the number of the property (Ii), a short description of the church, the date of the survey that was carried out to collect the data for the IDI Form, a note indicating whether it was possible or not to have access to the interior during the survey, some photos of the property and an unscaled floor plan of the church.

<table>
<tr><td rowspan="5">I6</td><td colspan="2">Church of São Mamede of Vila Verde</td></tr>
<tr><td colspan="2">Located in Felgueiras; it has a single nave and a chancel; it has a bell tower on the main façade and a vestry attached to the south facade of the chancel. There are heritage assets attached to the church</td></tr>
<tr><td colspan="2">Date of the survey: 15/03/2016
Access to the interior: Yes</td></tr>
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<table>
<tr><td rowspan="5">I12</td><td colspan="2">Church of the Monastery of São Pedro de Ferreira</td></tr>
<tr><td colspan="2">Located in Paços de Ferreira; it has a single nave with four spans; it has an apse, a narthex, a chancel and a belfry on top of an exterior wall.</td></tr>
<tr><td colspan="2">Date of the survey: 10/03/2016
Access to the interior: Yes</td></tr>
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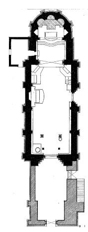
<tr><td></td><td></td></tr>
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Figure 6. Examples churches from the RR.

3.2 Analysis of the collected data

The examples presented herein illustrate some of the aggregated information that can be extracted from the collected data. Due to space restrictions, only a few cases are shown. It is however noted that some of the statistical analyses are only relevant because the architectural, structural and material characteristics of the 44 churches are similar, due to their geographical proximity.

Figure 7 presents an overall view of the state of conservation of the 44 churches in general and of some of their components in particular, namely the exterior walls (Figure 7b), the ceilings and roofs (Figure 7c) and the interior pavement (Figure 7d). As can be seen, most of the churches are in good condition, due to a series of actions for restoration, conservation and risk mitigation that have been carried out in several monuments of the RR since 2003. Figure 8 shows a view the Church of São Mamede of Vila Verde before and after the restoration works. Restoration works were not carried out in some of the churches yet, but are expected to be in the near future.

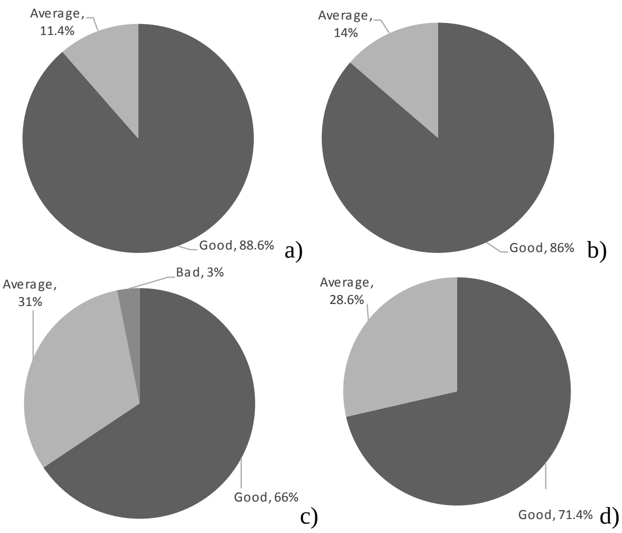

Figure 7. Statistics representing the overall state of conservation of the churches a), of their exterior walls b), their ceilings and roofs c) and interior pavement d).

Figure 8. Church of São Mamede of Vila Verde before (left) and after (right) the restoration works.

Figure 9 presents the analysis of a type of damage that is often found in these constructions: cracks or fractures. The analysis represents the percentage of cases in which this damage is found, across the several types of elements of the 44 churches. As can be seen, this type of damage is mostly found in the walls, particularly in the lateral walls of the nave. This type of damage is often an evidence of problems related to the roof, the foundations and drainage system, or to a lack of capacity of the walls to sustain out-of-plane thrusting from the roof system. However, conclusions can only be established by analysing the damage in the roof systems and the characteristics of the walls.

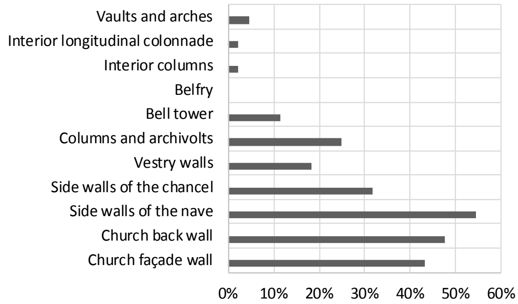

Figure 9. Damage statistics for cracks or fractures in the components of the 44 churches.

Focussing on the walls, for example, the survey of their thickness and number of leaves was carried out by analysing areas close to openings. In most cases, the thickness of the walls varies between 0.90m and 1.10m. It was also seen that 84% of the walls that were surveyed are double-leaf walls. It was however not possible to identify the type of cross section for the remaining 16%, in some cases due to the inability to access the inside of the church to analyse the zones near the openings. Future surveys will therefore need to complement the data inventory using ultrasonic wave and GPR tests. Based on this geometric survey, the walls were classified as *resistant* or *non-resistant* for out-of-plane loading. This classification was carried out by determining their slenderness ratio, one of the most relevant parameters when analysing the out-of-plane instability of these elements. These instability issues can be caused by intensive hazards such as earthquakes or wind, but also by slow-acting hazards related to the degradation of the roof system or to loads of large altarpieces leaning on these walls from the inside. The slenderness ratio of a wall is the ratio between its effective height h_{ef} (which depends on the end support conditions of the wall – free, pinned, fixed) and the effective thickness of the wall t_{ef} (which depends on the existence and the efficiency of the connection between the two wall leaves). Given the uncertainty of some of the in-situ conditions, the slenderness ratio analysis was performed for three hypotheses regarding h_{ef} and two scenarios for t_{ef} to simulate different conditions of lateral stability. Therefore, aside from the reference case where h_{ef} is considered to be the total height of wall h, cases reflecting the influence of the connection between the wall and the roof system were also considered. The cases where this connection is considered perfect ($h_{ef} = 0.7h$) and where this connection is considered to be non-existent ($h_{ef} = 2h$) were thus considered as limit situations. With respect to t_{ef}, the two considered scenarios are those that involve considering t_{ef} as the total thickness t of the wall and half of it (i.e. when there is no effective connection between the two wall leaves). The slenderness ratios that were determined were then compared with the limit value defined by Eurocode 8 (EC8, 2004) stating that for a wall to be considered *resistant*, its slenderness ratio cannot exceed 10. The results obtained for the façade, nave and chancel walls are summarized in Figure 10 that represents the percentage of *non-resistant* walls found for the 44 churches, considering the different hypotheses. The results show that, despite the apparent robustness of the walls of these churches, they may not exhibit adequate behaviour for out-of-plane loading. If the connection between the two leaves is not effective, most of the church walls will behave as *non-resistant* to out-of-plane loading. Therefore, more detailed surveys need to be carried out to obtain this information and mitigation measures need to be defined, if necessary, to ensure the robustness of the walls.

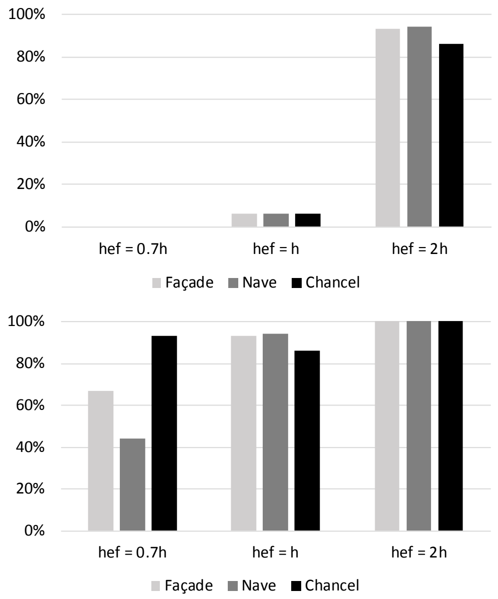

Figure 10. Statistics of *non-resistant* walls for out-of-plane loading found for the 44 churches: a) t_{ef} = t; b) t_{ef} = 0.5t.

As an example of a more detailed analysis that led to the development of mitigation measures to address this specific issue, reference is made to the works carried out in the Church of Gondar (Costa et al., 2007) in 2012. In this church, the exterior walls exhibited some degree of connection between the two leaves but external conditions were causing out-of-plane instability: a belfry sitting on top of part of the wall was causing an eccentric load on the external leaf (Figure 11) and the degraded roof drainage system around the belfry was allowing water to infiltrate inside the wall from the top causing additional out-of-plane thrusting. Since the connection between the two wall leaves was insufficient, the external leaf exhibited large out-of-plane deformations. In that situation, the structural conditions of the wall could be represented by the case where t_{ef} is 0.5t. and h_{ef} is somewhere between h and 2h. Given the results of Figure 10, mitigation actions were therefore carried out. These involved tying the masonry leaves and the corner walls with steel connectors, the injection of consolidation grouts and fixing the drainage system of the roof.

Figure 11. View of the Gondar church wall that exhibited out-of-plane deformations (a), view of two two-leaf stone connectors (b), injection of consolidation grouts (c).

Another type of the information that is collected by the IDI Form refers to changes made to the load bearing structural components of the churches that were carried out over time. The more common modifications that were found are extensions or enlargements of a given room, the cutting of new openings, the wall up of openings, and changes to the structure of the ceilings and roofs. Figure 12 presents the results of the survey of the structural changes that were carried out in the past to the chancel and nave of the 44 churches. As can be seen, a large proportion of the modifications involve changes in the roof structures and cutting new openings in walls. The availability of this information is particularly relevant when analysing the causes of certain existing damages to develop specific risk mitigation measures or when trying to estimate potential future damage and losses due to a hazard that depend on the global structural behaviour of the building.

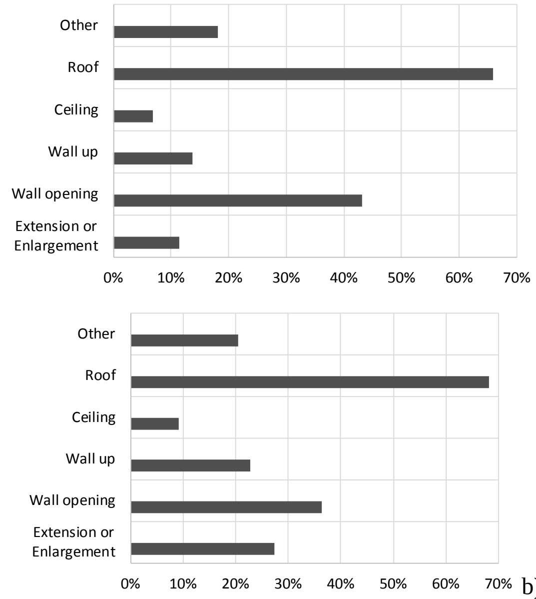

Figure 12. Statistics of structural changes that were carried out in the past to the chancel (a) and nave (b) of the 44 churches.

With respect to the existence of decorative cultural heritage assets attached to the buildings, the data collected by the IDI Form indicates that 84% of the churches have heritage assets attached to the walls and 34% of the churches have heritage assets attached to the ceilings. Most of these attached heritage assets are mural paintings, tiles, gilded woodcarvings or painted ceiling caissons. Figure 13 shows a few examples of these heritage assets and Figure 14 illustrates the proportion of these assets found attached to walls.

Figure 13. Examples of cultural heritage assets attached to the walls or ceilings of the churches.

The availability of data on the presence and type of attached cultural heritage assets is particularly important when estimating the potential damage and losses due to a hazard since a given hazard intensity that may not cause significant damage to the component supporting those assets may in fact cause a substantial loss in value to those assets. Moreover, when defining risk mitigation measures that involve the components supporting those assets, the type of mitigating action and/or solution needs to account for the presence of those assets. A similar line of reasoning needs to be applied when developing emergency measures for those components after a disaster.

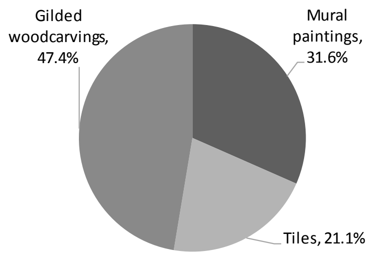

Figure 14. Statistics of cultural heritage assets attached to the walls of the churches.

With respect to the surrounding environment of the churches, one type of information that is collected by the IDI form is the type of slope of the terrain in which the churches are built. This data is particularly relevant for risk management procedures related to hazards such as landslides, earthquakes or heavy rains. To illustrate the type situations that are found, Figure 15 represents the distribution of the churches along the four classes of slope of the terrain that were considered. As can be seen, only about 7% of the churches are located in a flat terrain. Therefore, most of the churches might be vulnerable to the previously referred hazards. In addition, it was also seen that, when in the presence of a terrace, about 25% of the cases do not have retaining walls or have retaining walls in bad conditions (Figure 16). As such, this data needs to be accounted for when performing risk analyses involving the referred hazards.

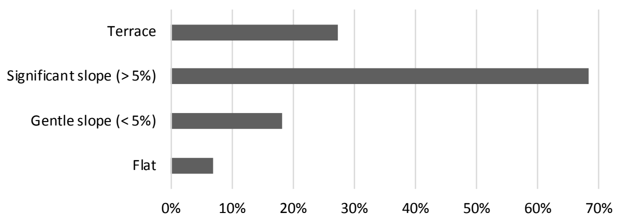

Figure 15. Slope of the terrain where the churches are built.

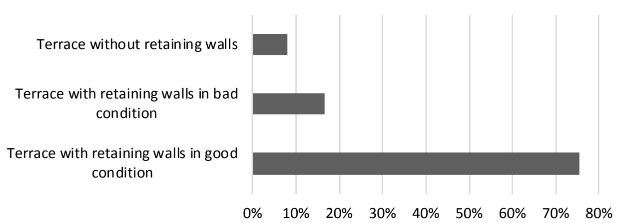

Figure 16. Existence and conditions of retaining walls when the terrain where the churches are built is a terrace.

4. FINAL REMARKS ON THE ROLE OF THE COLLECTED DATA FOR CULTURAL HERITAGE RISK MANAGEMENT

The possibility of establishing the conservation state of cultural heritage assets and identify the sources of existing damage and/or of ongoing degradation phenomena through systematic surveys provides fundamental data for risk mitigation. Potential losses can be estimated by correlating this information with the type of intensive or extensive hazard involved and the urgency of mitigating measures can be determined from the likelihood of the hazard occurrence. Moreover, having a detailed knowledge about the materials, geometry and building processes of these cultural heritage assets also allows estimating risk mitigation costs and perform cost-benefit analyses to minimise heritage losses. By extending this type of analyses to a large group of cultural heritage properties with similar architectural characteristics, common issues can be more easily identified. As such, the planning of risk mitigation actions is also facilitated.

Finally, it is noted that surveying data on decorative cultural heritage elements attached to the constructions along with the more technical and structural data, provides a more complete and multidisciplinary view of the immovable heritage asset. As referred before, having this dual information is vital for risk and loss assessment of cultural heritage since a more realistic view of the expected loss in value and of the existing constraints for defining risk mitigation actions can be achieved.

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