Virtual Reality Technology applied to the maintenance of building roof

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Abstract

A building's roof cladding of ceramic tiles constitutes a component of its surrounding and possesses an important function in the performance of a building, namely in its protection against the permeation of moisture and rain water and, as such, requires greater attention with regard to the analysis of its degradation process. To this end, it is necessary to know its components, conduct a survey of the main anomalies that occur in this type of roof, the respective causes and the adequate interventions, in order to plan maintenance strategies and, thus, meet the durability requirements of the materials used. In this study a characterization of the types of elements that compose this cladding is taken, as are the principal anomalies, probable causes and repair methodologies associated to the covering being analysed. The information collected serves as a basis in the implementation of an application using new information and visualization technologies, to support the maintenance planning of building roof. The software tool allows the identification and characterization, in an intuitive and interactive manner, of roofing elements, as well as the association and characterization of anomalies, probable causes and recommended interventions of the same, following the proceedings of an inspection. Through the virtual model it is possible to attribute colours to the analysed elements, according to the gravity of the anomaly, and, thus, allowing for visualization in the building's virtual model of the elements needing urgent intervention, supporting the maintenance planning. Additionally the application permits the creation, intuitively, of inspection sheets and anomaly sheets associated with the analysed cladding elements. The present work contributes to the use of interactive and computerized tools as a support to maintenance activity.

Keywords: *Anomalies, Inspection, Maintenance, Virtual Reality*

1. Introduction

The present work has as its main objective the development of a technological tool to support the maintenance activity of pitched roofs in buildings, with resort to new information and visualization technologies.

The cladding is the most effective element of a building's surrounding, and it has to efficient in the face of mechanical, thermal, solar radiation and water action (Harrison, 1996). The functional requirements to be fulfilled are essentially defined in terms of habitability, safety, durability and economics. Although several cladding materials can be applied in the execution of pitched roofs, in Portugal the most frequently applied covering is the ceramic tile. The tile cladding ensures the continuity of the architectural tradition, allows the creation of visual effects through the variety of shapes and ancillary parts, offers a good performance in the face of atmospheric agents and a high durability and is, furthermore, an ecological product, for it is non-toxic, is renewable and biodegradable (Garcez, 2009). As the cladding performs a predominant role in the protection of buildings, namely against water leakage, it requires a greater attention in regards to the analysis of its deterioration process.

The developed virtual model allows the creation, in an interactive manner, of inspection sheets on anomalies associated with ceramic tiled pitched roofs, which support the maintenance activity.

2. Pathology and maintenance of ceramic tiling on building's roof

As a way to optimize the inspection process and the diagnosis of anomalies associated with the coverings it was necessary to create a classification system that encapsulated the information collected on this theme.

Therefore four categories on the elements typology were considered: the elements that compose the covering support structure (SS); the ones that constitute the current surface of the covering (CS); the elements considered as singular covering points (SP); the ones that form the rainwater draining system (DS).

The study undertaken by Rocha (2008), directed at the analysis of pitched roof anomalies, concludes that a greater number of anomalies occurs in the singular covering points, since more precision is required in its execution (Figure 2.1).

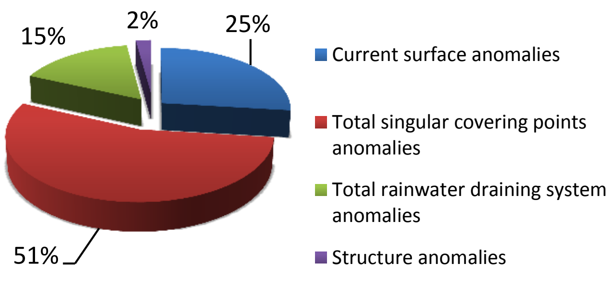

Figure 2.1 – Distribution of anomalies by covering zone, considering the number of occurrences, adapted from Rocha (2008).

To undertake an adequate covering maintenance activity it is essential to deepen the knowledge on the anomalies that might occur and, also, evaluate the most probable causes, as to adequately in-service interventions these structural elements. This in-depth analysis seeks to design a supporting database for the implemented application on maintenance planning of roofs. The main anomalies associated with the different elements described above, are contained within the database. Is mentioned the possible causes of the anomalies and recommended interventions possible for restructuring. To maintain the ease in structuring the database, the causes and the intervention are both linked to the anomaly. The collected information has been separately sheeted, being that, in the use of the application, a clear linkage is allowed by the grouping of that same information. Table 2.1 contains two examples of anomalies associated to the type of element, the current surface and the singular covering points, presenting the causes and recommended interventions. This example consists of a sample combining all the information.

In several instances, the state of degradation of the roofing elements requires numerous corrective interventions, which leads to a significant rise in building use costs, as such it is necessary to determine intervention priority criteria and thus establish an efficient maintenance methodology and lower intervention costs. There are numerous criteria to do so, but, as a way to simplify this field in the application, only one criterion, relative to the gravity of the anomaly, has been introduced into the model.

With all the content, serving as the basis for the application, being collated the next step consists of its implementation through technological tools.

3. Implementation of the virtual model

For the implementation process of the 4D cladding maintenance support model, Virtual Reality technology is used. Virtual Reality (VR) can be described as a set of technologies that, supported through the use of computers, simulates existing or idealized space (Burdea & Coiffet, 2003). This tool allows users to interact with environments modelled three-dimensionally (3D). This application was elaborated as a continuation of the interactive models developed within the research project carried out by Sampaio et al. (2009), which consisted of promoting the monitoring of maintenance plans for building lighting elements. The objective of the 4D model developed is to permit the visualization, through virtual environments, of information associated with roof covering element degradation. Thus, through the interaction with the model, it should be possible to support the carrying out of building inspection within strategic maintenance plans and identify, visually, the severity of repair works needed to be undertaken. As a case study a 3D model, accompanied by representational 3D covering elements, was created using the *AutoCad* system (AutoCad, 2012). Afterwards, the 3D model was enhanced in its representation, so as to obtain a more realistic looking model, with the *software 3dsMax* (3D Studio Max, 2012). The building's 3D model, with the covering elements expressed in distinct layers, was transported to the *EON Studio* system (EON, 2012) so as to be associated to its model interaction ability. Figure 3.1 illustrates the transformation carried out on the building's 3D model.

Table 2.1 - Examples of anomalies with the respective causes and intervention recommendation.

Element type	Anomalie	Causes	Intervention
Current surface	Cracking of cladding elements 	1. Supporting structure's deformation 2. Lack of walkways on roofs 3. Placing heavy equipment on the roof 4. Excessive amount of fixations of tiles to support 5. Effect temperature and moisture's variation	Replacement of damaged elements
Singular covering points	Insufficient size of the trim 	1. Deficient execution	Element removal and placement of new higher height's trim

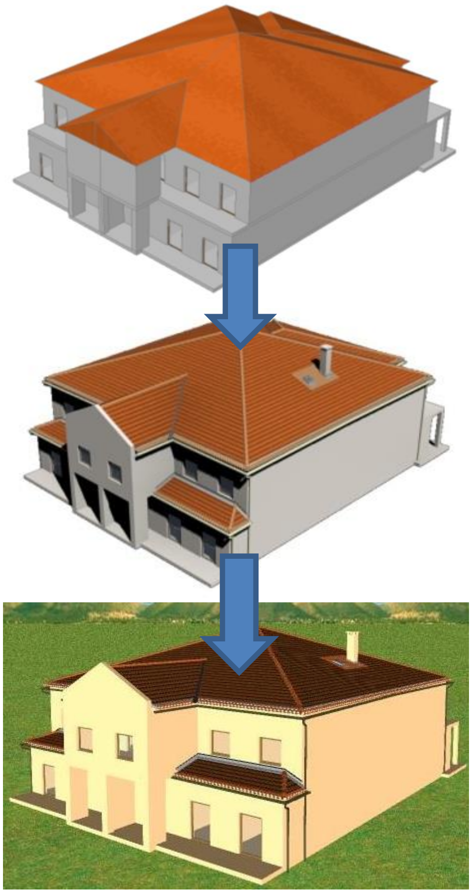

Figure 3.1 – Transformation carried out in the 3D model.

The roofing maintenance and inspection support VR application incorporates a database, created through the *Microsoft Office Access* system (Access, 2013), with all the data regarding anomalies, probable causes and recommended interventions. The connection between the 3D model and the database was established by programming carried out in *Visual Basic* (Visual Basic, 2013). The implemented interface allows the user to perform, intuitively, an inspection to a pitched roof. Figure 3.2 displays the application's main interface, consisting of the following zones:

1. **Building**: enables the identification of the building and the inclusion of relevant characteristics for the carrying out of inspections;
2. **Virtual model**: interactive window with the 3D geometrical model;
3. **Element identification**: each of the cladding elements is initially identified in order to create a database of its own of elements to be monitored;
4. **Element research**: identified element selection from within the database;
5. **Element characteristics**: visualization of the selected element's characteristics;
6. **General inspection characteristics**: indication of the conditions in which the inspection was carried;
7. **Next inspection date**: future inspection planning.

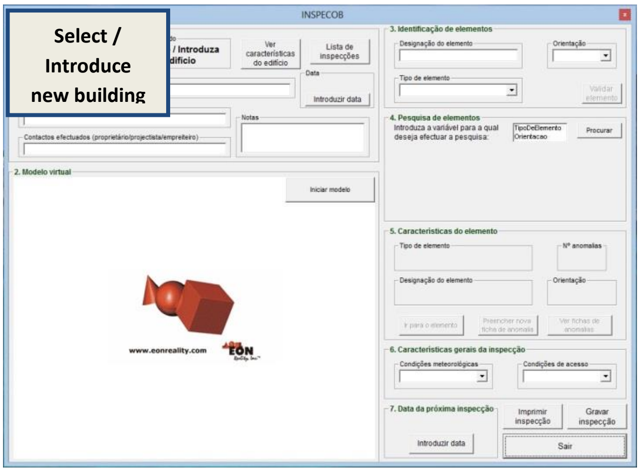

Figure 3.2 – Application's main interface.

3.1 Building identification

The first step in using the application is, naturally, to identify the building to be analysed, through the command "Select / Introduce new building", shown in the main interface, which launches a new window, allowing the completion of fields on building identification, its general and roofing characteristics (Figure 3.3).

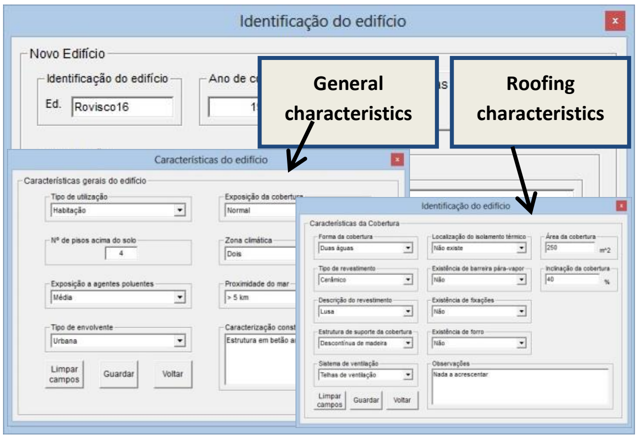

Figure 3.3 – Building characterization interface.

The data associated with the general characterization of the building and the corresponding roof cladding is then archived in the application's database. The information is made available for selection and to be associated with any records on inspections that might be undertaken on the building's cladding. Upon registering the building and its characteristics the "List of existing buildings" is updated, making the register ready for selection.

To perform an inspection in a previously identified building the initial data necessary for the inspection sheet identification is introduced into zone "1. Building" of the main interface: the sheet inspection number's; the person responsible for carrying it out; the inspection date and objective; contacts made while inspecting the covering;

and some notes on the inspection (Figure 3.2). On selecting the building it is possible, through the "View building characteristics" command in the main interface, to observe the inspected building's characteristics and, through the "Inspections list" command also in the main interface, to access the inspection sheets previously carried out on that building. Additionally, it is necessary to characterize the meteorological conditions on the day of the inspection, as well as on the method used to access the roof. The designation of these characteristics is made in zone "6. General inspection characteristics" (Figure 3.2), also included in the main interface.

A window allowing the viewing of the building's virtual model is displayed in the main interface. The access to this model is done through the "Initiate model" control button, being that a file created in the *EON* system, with the extension *.eoz, must be selected (Figure 3.4).

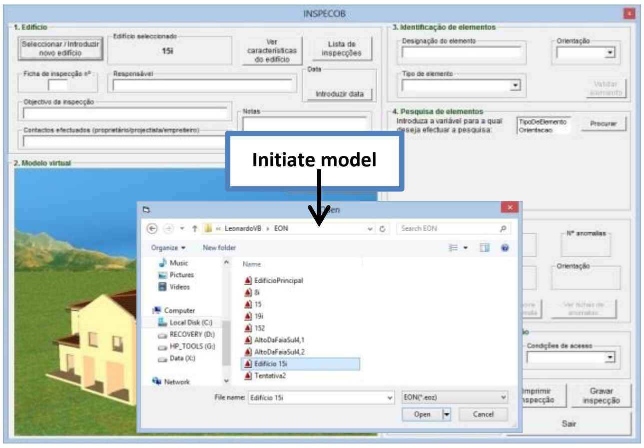

Figure 3.4 – Selection of the virtual model.

3.2 Element Identification

Upon opening the selected file it is possible to manipulate the model, through functions that allow the moving of a camera around it and by the selection of covering elements to be identified and monitored. Each element to be monitored must be identified so as to be included in the application's database. If the element is not yet present in the database an informative window on this state is displayed (Figure 3.5), being that identification should then be inserted. During the identification process the camera must be focused on the element so the coordinates, of position and orientation, to be associated to it are accurate, thus allowing subsequently an adequate visualization of the element under analysis.

The element identification is carried out in zone 3 of the main interface (Figure 3.2). The element identification zone is comprised of (Figure 3.5): "Element designation", where the user is able to name the element; "Type of element", in which the type of element (current surface, singular covering points, support structure or drainage system) should be selected; and "Orientation" of the covering element's exposure according to cardinal points. The type of element corresponds to the organizational structure present in chapter 3, since the anomalies have been grouped, to facilitate their search in the database, according to the type of element.

The entered data is then archived into the database, characterizing the monitored element and becoming linked to it. Additionally the position of the camera associated to the element is registered, thus being available for use in subsequent interactions.

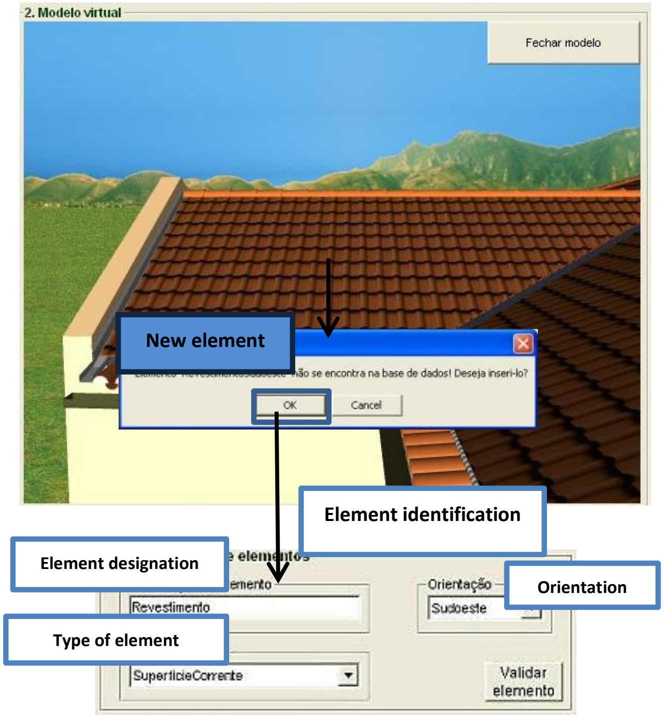

Figure 3.5 – Element identification.

For the display of identified elements an "Element search" section has been developed (zone 4 of the main interface), which facilitates user interaction with the virtual model. The identified element search can be realized according to two criteria: Type of Element and Orientation. Upon selecting the element it is possible to view its characteristics in the "Element characteristics" section and, through the "Go to element" command, immediately view the selected element in the virtual model (Figure 3.6).

Section 5 of the main interface also contains two commands; one for viewing the selected element's previously associated anomaly sheets and one to fill out a new anomaly sheet.

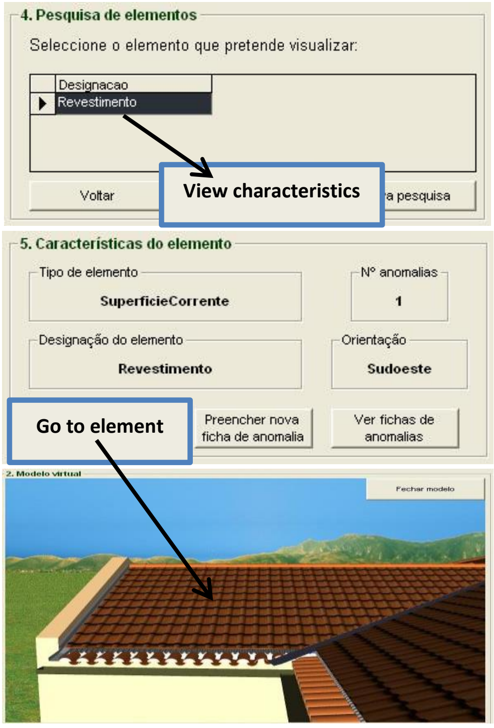

Figure 3.6 – Research, selection and visualization of the identified element.

3.3 Anomaly sheet

The filling out of a new anomaly sheet or the viewing of existing sheet's data is made available through another interface entitled "Anomaly sheet". The anomaly sheet is comprised by 4 sections: Anomalies / Causes, Anomaly characterization, Intervention and Anomaly photo (Figure 3.7). The first and third sections depend on parameters available on the database created, while the remaining sections are freely completed by the user.

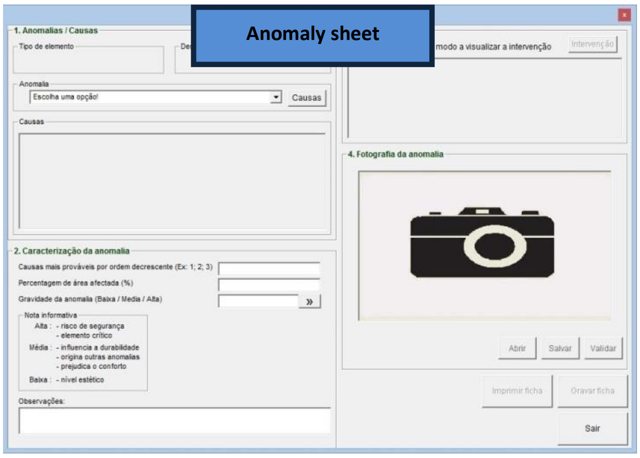

Figure 3.7 – Anomaly sheet interface.

In the anomaly sheet the scroll-down menu referring to the "Anomaly" field shows the anomalies that have been registered in the database in association with each of the types of elements. So, for example, in relation to the "Covering" element, belonging to the "Current Surface" group, the associated anomalies are shown in the scroll-down menu (Figure 3.8 shows part of that list).

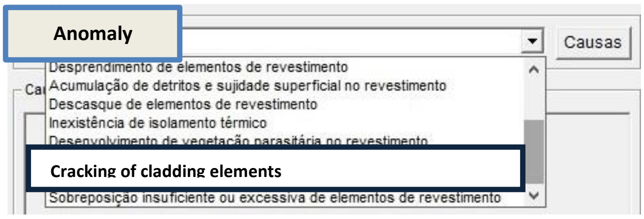

Figure 3.8 – Anomaly selection.

The causes and intervention modes were equally associated to the anomalies, and, therefore, by selecting the respective control buttons, the probable "Causes" and recommended "Intervention" fields are filled-out with the database records connected to the selected anomaly.

For a better characterization of the anomaly a few fields, of direct filling, have been created to enable the user to add to the information already selected (Figure 3.9). The severity of the anomaly can be characterized according to three parameters (Low / Medium / High), reflecting the previously realized study. The value shown in this field is then used in the element's colour change in the virtual model, through the emission of information to *EON*, changing itself according to the severity of the anomaly, green for low, yellow for medium and red for high.

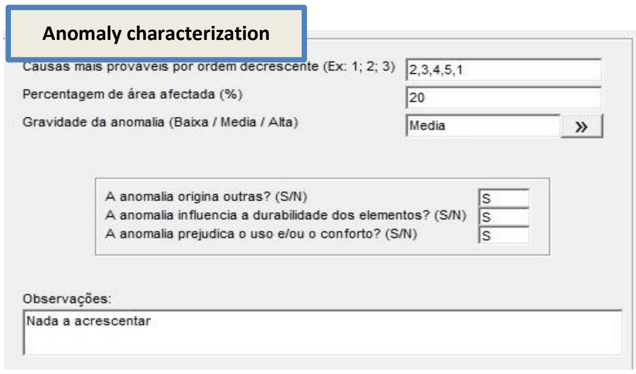

Figure 3.9 – Section of anomaly characterization.

Following the description of the anomaly and the indication of its probable causes, the "Intervention" control button should be selected as to view the recommended intervention in field 3 of the inspection interface (Figure 3.10).

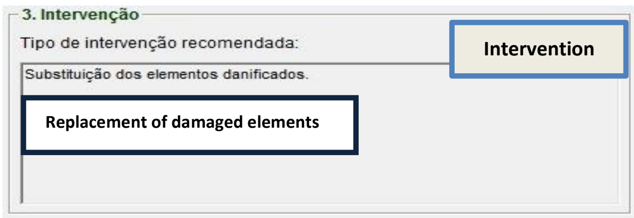

Figure 3.10 – Recommended Intervention for anomaly repair.

The inspection sheet interface also comprises a photo insertion zone (4) (Figure 3.11). Thus it is possible to add photographs taken in the inspection location or other images related to the element being analysed, forming a considerably relevant complementary information for the subsequent study of repair/maintenance relative to the observed severity. The insertion of two images has been made possible. This way a broader view photograph, framing the anomaly in space, and another picture, more focused on detail, can be included.

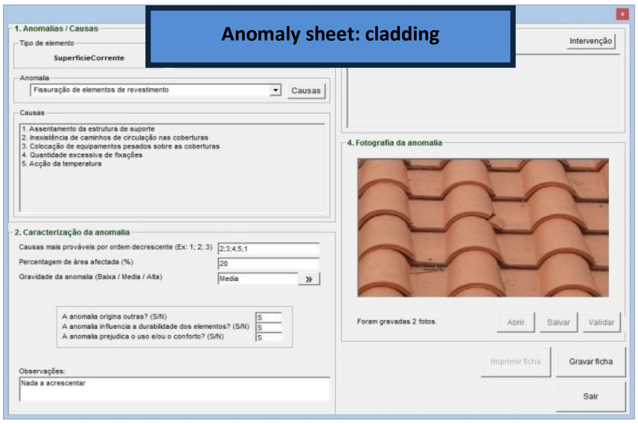

Figure 3.11 – Completed anomaly sheet.

On completing the data registration in the anomaly sheet the "Save sheet" command becomes available. The command is associated to a programming routine that saves all the information entered into the sheet in the building's database, linking it to the inspected element, as well as to the images folder.

3.4 Chromatic routine assignment

Additionally, when the "save sheet" command is activated, besides registering the data into the anomaly sheet, it triggers another routine responsible for the colour change in the analysed element.

The attribution of colours, that corresponds to the degree of severity in the analysed element's functional damage, during the inspection of the actual cover, allows the user to understand, in a very intuitive manner, the need to act with more or less urgency, its area and extension and, creates an alert hierarchy for the inspected elements (Figure 3.12). This ability is one of the most relevant in the use of VR as a maintenance visual support tool.

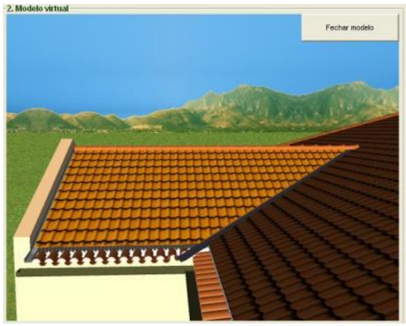

Figure 3.12 – Colour alteration of the element.

Finally, with all of the anomaly's information saved in its sheet it is possible to register the selected and created data into an electronic file, in a *pdf* format. By selecting the "Print sheet" command the respective file, in which all the fields are completed automatically with the data from the anomaly sheet, is created (Figure 3.13). Lastly, through the "Exit" control button, the user returns to the main interface.

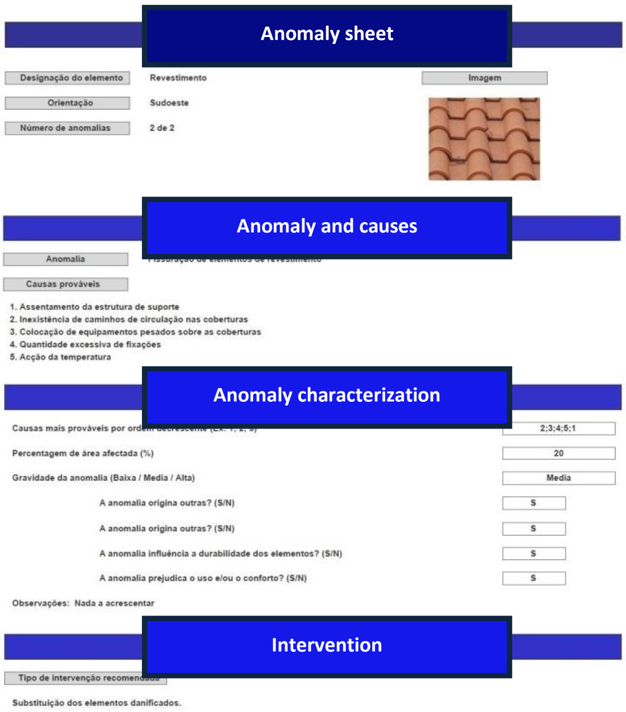

Figure 3.13 – Anomaly sheet as a PDF.

3.5 Future inspections – update of the anomaly sheet

The appliance also makes it possible to update the anomaly sheet's data. Therefore, when carrying out a second inspection to observe whether any repair intervention has been made (analyse whether the anomaly has been eliminated) or reanalyse the severity degree of the anomaly (if it is stable or if it has deteriorated) it is possible to alter the previously introduced data. To do so it is necessary to access the sheets of previous anomalies and, eventually, merely change the fields concerning the anomaly's state.

Accessing the existing anomaly sheet, the "Change sheet" command is displayed, which, when selected, permits modifications in the "Anomaly characterization" field, and allows the user to annotate freely the state of the anomaly in the "Notes" field. The new field allows for the evaluation of the anomaly's new state ("State"), and the saving of the edited sheet (Figure 3.14). The "State" field indicates whether or not an intervention on the anomaly has been carried out, with "to repair" or "repaired". This sheet edit command has been created so the registered information on inspections conducted in different dates can be reused and updated. Thus, the history of the building's inspection / maintenance / repair activities can be monitored.

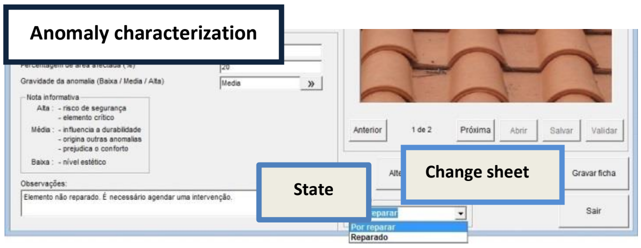

Figure 3.14 – Sheet amendment command.

When saving the changes made, the database fields regarding the anomaly in question are updated and, the element's colours, associated to the anomaly, are eventually adjusted in the virtual model. It is thus possible to view again the building's current conservation state.

3.6 Inspection sheet

Finally, in the main interface's bottom right corner, three current use control buttons on computational applications have been included (Figure 3.15): the "Save inspection" button allows the user to save all the data introduced in this interface, to a database for future use, meaning that, the initial information on the data, objective and inspection condition, as well as all the data related to anomalies observed and registered during inspection, is archived; the "Print inspection" button that allows the user to create a PDF file for printing; the "Exit" button that makes the exiting of the program without saving the registered information possible. A field of interest to support the maintenance planning by requiring the introduction of the next recommended inspection date has also been inserted, making it possible for the user to plan future inspections based on what is currently registered. Naturally, if a new inspection is carried out in the next recommended date, the anomaly sheets should be reused and updated.

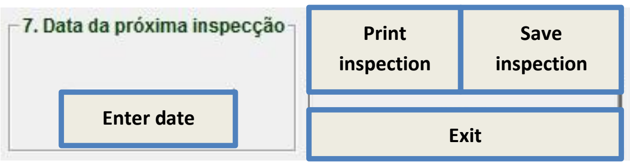

Figure 3.15 – Application's final commands.

The "Print inspection" command allows the creation of an organized PDF that provides the building's general data and information on the inspection activity performed on a given date, as well as a summary of the observed elements. Therefore, the generated document contains all of the information on the building, the inspection's general aspects and, all of the inspected elements with their respective anomalies, condition and gravity of degradation (Figure 3.16).

Figure 3.16 – Inspection sheet as a PDF.

4. Applying the model in real cases

Following the description of the process in implementing the computer application in the maintenance of roofing, then it's proceeded to apply it to real cases. The information collected in 5 inspections carried out by other technicians (information collected through sheets or reports) is then inserted into the application. Thus, it is possible to compare the current mode of roof inspections through the use of the proposed application.

It was verified that, because the inspection sheets corresponded to different objectives, the necessary data to fill out all of the fields was lack. Another difficulty in all inspection sheets, is identifying the anomalous element, since the sheet does not indicate the area in which the anomaly has occurred, and as such, it becomes difficult to identify the anomalous element on the virtual model. Therefore, the elements have been identified in different roof areas, to view the different colours associated to deterioration severity.

In regards to the report format, as it is a technical note, no information on the building characteristics was included, since the main interest is in explaining the interventions' implementation processes. The developed application is oriented towards the recording of anomalies and their full description, to support the delineation of intervention plans and, as such, does not present as many details at the level of repair works.

The information relative to the totality of the information collected was introduced into the application, simulating different instances of inspection. Figure 4.2 illustrates the appearance of the building's virtual model based on the data obtained for each case. In the display window it is possible, through colour attribution for each of the damaged elements, to detect which of the buildings requires more urgent intervention.

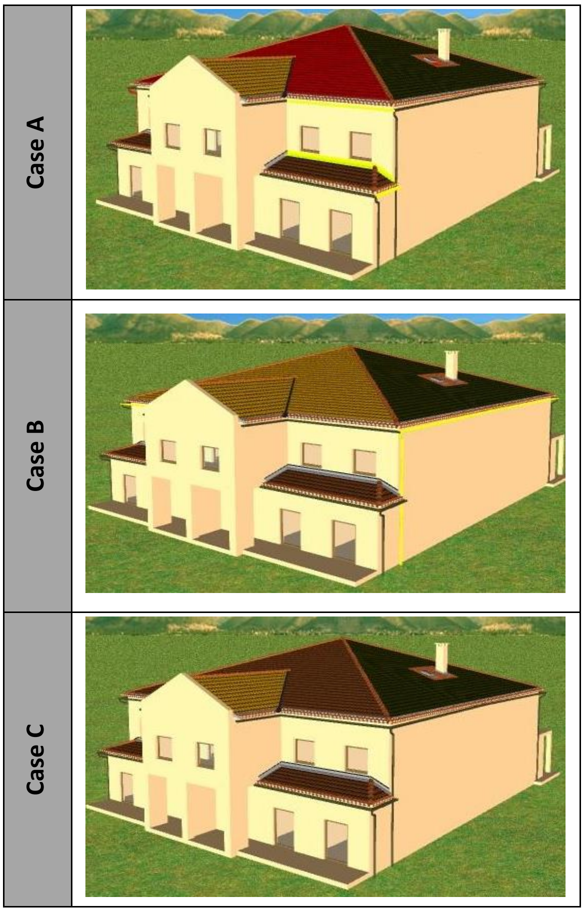

Figure 4.1 – Virtual models of buildings related to the different inspection cases applied (Cases A, B and C).

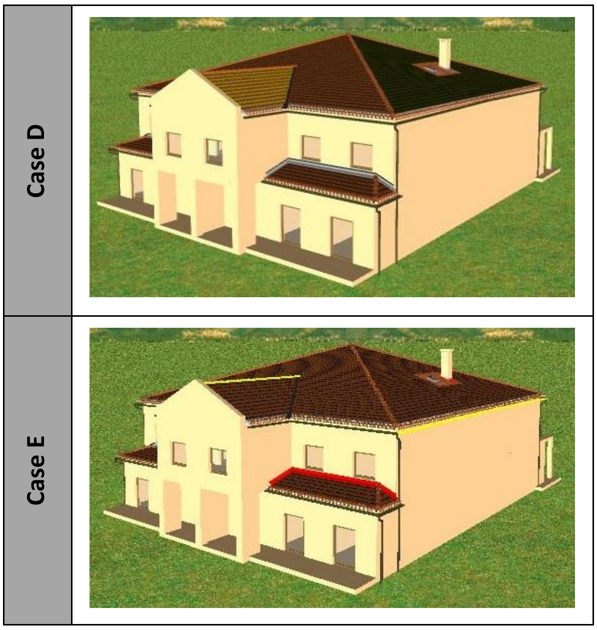

Figure 4.2 – Virtual models of buildings related to the different inspection cases applied (Cases D and E).

Assuming that the buildings represented in Figures 4.1 and 4.2 belong to a housing stock, this viewing capacity allows for the housing estate manager to elaborate an intervention plan according to the urgency of each building. Thus, intervention priority should be given to the building which condition requires greater urgency, in this instance case A.

Additionally, by observing an entire group of buildings it is possible to infer as to which element is the most affected and, through the support of cause and effect analysis, verify if any anomaly is common to all buildings, thus raising the question of a deficient project detail or mode of roofing elements implementation. This situation can be verified by viewing Figures 4.1 and 4.2, in which it can be seen that cases A, B, C and D present similar severity levels in twofold coverings, which might indicate the presence of the same anomaly.

5. Conclusions

The main objective in implementing the application has been to aid the inspector, providing him with, in an intuitive manner, all the information related to anomalies associated to roof covering elements and, thus, make the inspection more reliable and reduce uncertainty.

The developed application allows the inspection of roof cladding through the developed computer tool, which features interactive graphic mechanisms capable of dynamic the inspection activity. It is possible for the user to introduce, visualize and alter the building characteristics, link anomalies to elements, by monitoring through the building's 3D virtual model, and viewing in that same model, all the colour changes that have taken place due to the attributed severity of the anomaly. The development of this visual component permits, in future inspections or while planning maintenances actions, the viewing, through the buildings' virtual model, of the covering's state of deterioration and, so, the defining of which are the priority intervention elements.

It is intended that, with this application, the user might, besides conducting inspections at any time, access the registered information and the virtual model and, thus, supported by the historical, adequately plan the roof maintenance. Such will only be possible by storing all the information inserted into the application, as well as the changes made to the building's virtual model in a previous inspection.

Since the application is based on clarified and systematized information, there can be a reduction in inspection subjectivity, and it may be used by different technicians. Thus, the information collected by technicians becomes clear and objective, which permits an adequate analysis of the inspection data.

The applicability of this model might be interesting for a housing estate manager when it has a set of buildings, for which inspections and interventions need to be planned. The application allows them to be carried out in a more rational manner, reducing the global costs and the risks for users.

This application was developed in order to be intuitive and interactive, making it more of a user-friendly environment, and facilitating the practice of maintenance activity.

As a future development, it is suggested the enhancement of the user's interaction with the building's virtual model, namely, through functions that permit the visualization of structural elements and highlighting of the same.

Applying the model to other real cases and future inspections, by a group of technical inspection, has a great interest component, so that is carried out further analysis and thus determine the aspects to improve the model. The application of the model should be conducted at several buildings with different types of pitched roofs.

It is proposed to apply this tool to other components of a building like in floors and, in roofs it is suggested to implement a 3D flat roof model, to create a virtual model that supports maintenance of all elements of a building.

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