Maintenance of Building Components Supported on VR technology

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ABSTRACT: *The text presents the description of a research work that has as its main objective the development of a technological tool to support the maintenance activity of buildings, with resort to new information and visualization technologies. There were analyzed three main components of the building: roofs, facades and interior walls. A building's roof covering of ceramic tiles constitutes a component of its surrounding and possesses an important function in the performance of an edifice, namely in its protection against the permeation of moisture and rain water; Facade coatings play a significant role in the durability of buildings, since they constitute the exterior layer that ensures the protection of the wall against the aggressive actions of physical, chemical or biological nature; The paint coating applied to interior walls conveys their aesthetic character, performs an important function of protection, and is exposed to agents of deterioration related to the building use. A survey of the main anomalies that occur in these components, the respective causes and the adequate interventions, in order to plan maintenance strategies was conducted. The information collected serves as a basis in the implementation of applications using interactive visualization technologies, to support the planning of building maintenance. During this work the basic knowledge related to the materials, the techniques of rehabilitation and conservation and the planning of maintenance is outlined and discussed in addition, methods of interconnecting this knowledge with the virtual applications were explored. The implemented prototypes were trialed in real cases. This research work brings an innovative contribution to the field of maintenance supported by emergent technology.*

Keywords: Construction, Maintenance, Interaction, Virtual Reality

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1. Introduction

The main aim of a research project PTDC/ECM/ 67748/2006 [1], was to develop virtual models as tools to support decision-making in the planning of construction management and maintenance. Virtual Reality (VR) technology can support the management of data throughout the lifecycle of a building, allowing interaction and data visualization.

Factors such as the constant exposure of the coating materials, like ceramic tiles in roofs and facades, stones and painted surfaces in facades and interior walls, to the weather, pollutants and the normal actions of housing use, linked to its natural ageing and, in some cases to the unsuitable application of construction materials or systems of painting give rise to its deterioration and to the appearance of irregularities, which can negatively affect its performance as both an aesthetic and a protective element. A building's roof covering 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. The weather significantly influence the state of use of peripheral walls of the building once the humidity through the wall thickness causing anomalies in the inner surface of the wall. According to Lopes [2], in normal conditions of habitation use and when correctly applied, a paint coating can remain unaltered for about five years. Since these building components is exposed to bad atmospheric conditions and natural use of the house, the materials frequently show an evident degree of deterioration, requiring maintenance interventions. To perform maintenance activities a survey of failures in the building must be conducted in order to arrive at the best solution for repair and maintenance.

Establishing suitable maintenance strategies for this type of coating is based on the knowledge of the most frequent irregularities, the analysis of the respective causes and the study of the most adequate repair methodologies. Currently, the management of information related to the maintenance of buildings is based on the planning of action to be taken and on the log of completed work. The capacity to visualize the process can be added through the use of three-dimensional (3D) models which facilitate the interpretation and understanding of target elements of maintenance and, furthermore, the possibility of interaction with the geometric models can be provided through the use of Virtual Reality (VR) technology. The developed VR models can be considered as useful computer tool with advanced visualization capacities in the maintenance field.

The kind of building material that composes the roofs, façades and the interior wall has a continuous lifestyle, so requires the study of preventive maintenance (the planning of periodical local inspections) and of corrective maintenance with repair activity analysis. The models of maintenance facilitate the visual and interactive access to results, supporting the definition of inspection reports, whether in new constructions or those needing rehabilitation.

The three-dimensional (3D) model of the building linked to a data base concerning maintenance produces a collaborative virtual environment, that is, one that can be manipulated by partners interested in consulting, creating, transforming and analyzing data in order to obtain results and to make decisions. Namely, inspection reports can be defined and consulted by different collaborators. The process of developing the interface of each application considers these purposes. These applications can be easily transported to any building place in order to obtain adequate anomaly surveillance and a consequent methodology of rehabilitation, supported on the data base. The interaction and the data visualization allowed by the models turn these applications simple and direct to work with.

2. Interactive Applications

The implemented prototypes, concerning three building components, roofs [3], facades [4] and interior walls [5], incorporate interactive techniques and input devices to perform visual exploration tasks. To support each system a data base was created which included a bibliographic research support made in regard to the closure materials used in the roof, and interior and exterior walls of a building, anomalies concerning different kinds of covering material, and corrective maintenance. Repair activities were also studied. The programming skills of those involved in the project had to be enhanced so that they could achieve the integration of the different kinds of data bases needed in the creation of the interactive model. The interactive applications support on-site inspections and the on-going analysis of the evolution of the degree of deterioration of the coating materials. The following computational systems were used in there development and the scheme of links between software is presented in Figure 1:

- **AutoCAD**, in the creation of the 3D model of the building (based on drawings presented in Fig. 2);
- **EON studio** for the programming of the interactivity capacities integrated with the geometric model (Fig. 3 shows the main interface);
- **Visual Basic** in the creation of all the windows of the application and in the establishment of links between components;
- **Microsoft Access** on the definition of a relational database.

2.1 The VR Model of Roofs

The roof covering is the most effective element of a building's surrounding in its edification performance, and, as such, must be efficient in the face of mechanical, thermal, solar radiation and water action [6]. The functional requirements to be fulfilled are essentially defined in terms of habitability, safety, durability and economics. Although several covering materials can be applied

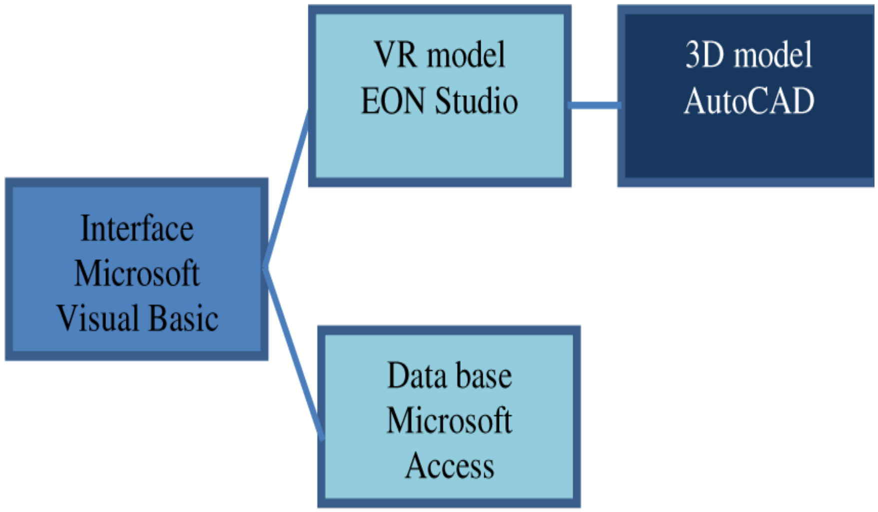


Figure 1. Scheme of links between software

in the execution of pitched roofs, the most frequently applied covering in Portugal is the ceramic tile. The tile covering 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 [7]. As the covering performs a predominant role in the protection of buildings, namely against moisture permeation, it requires a greater attention in regards to the analysis of its deterioration process.

The developed VR application supports the inspection activity [3]. Concerning the pathology analyses and the maintenance planning, as a way to optimize the inspection process and the diagnosis of anomalies associated with the roof covering, 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**).

An in-depth study on the anomalies that might occur, and the most likely causes associated with the different elements of the roof, are contained within the database. To each anomaly one or more probable causes in its occurrence is specified, as is the recommended intervention as a way to eliminate it. To maintain the ease in structuring the database, the causes and the intervention are both linked to the anomaly. Table I illustrates wo examples of anomalies associated to the type of element (current surface and singular covering points), respective provable causes and recommended interventions.

The implemented interface (Figure 4) allows the user to perform, intuitively, an inspection to an inclined roof. The first step in using the application is, naturally, to identify the building to be analyzed and the respective roofing characteristics. 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 (Figure 4). During this process the camera must be focused on the element so the coordinates, of position and orientation, to be associated to it are accurate, thus being available for use in subsequent interactions (selection and visualization of an identified element, Figure 4).

The filling out of a new anomaly chart (Fig. 5) or the viewing of existing charts' data is made available through the interface anomaly chart accessed by the main interface. In the anomaly chart 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

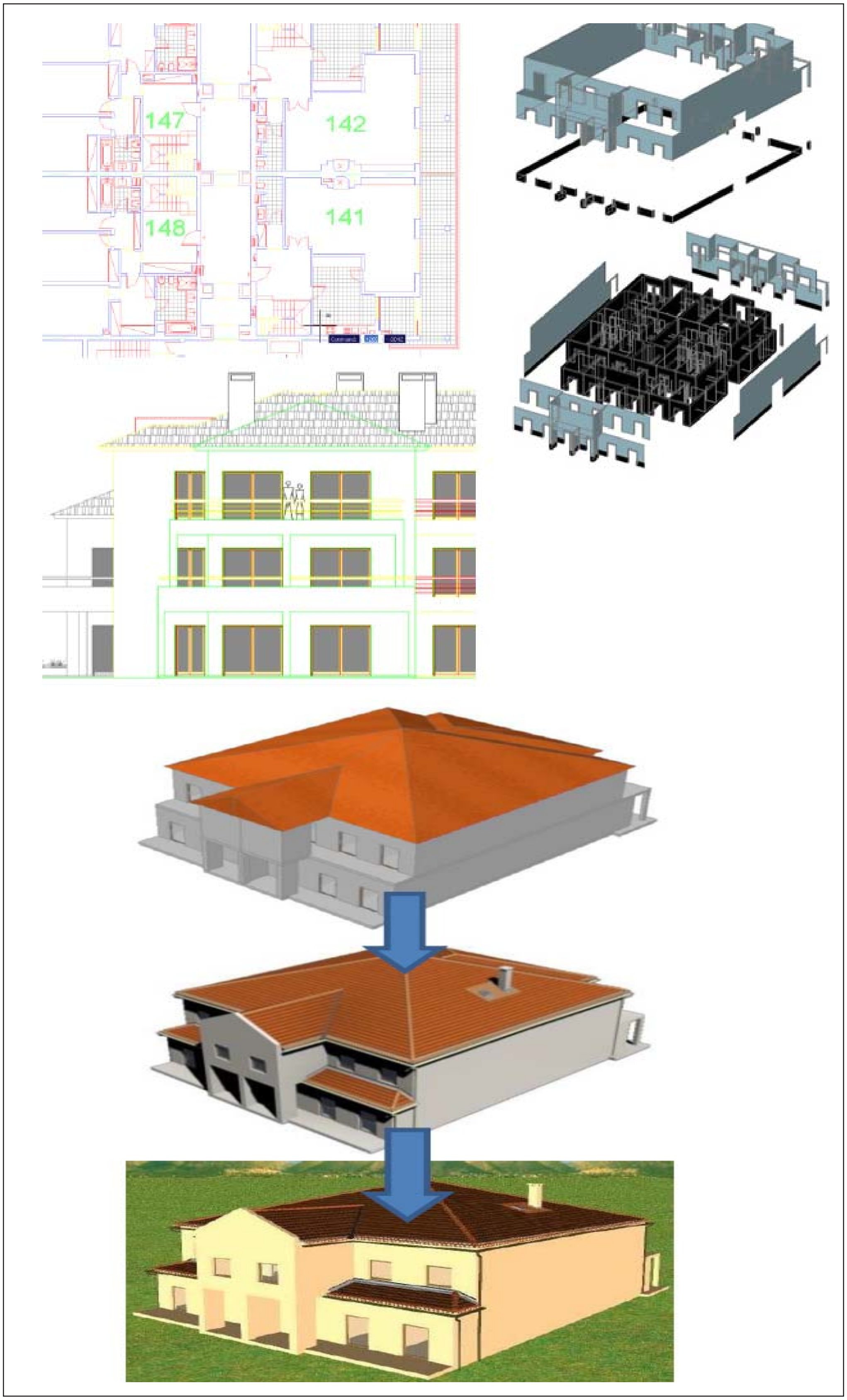


Figure 2. Technical drawings and the 3D model of the building

relation to the covering element, belonging to the current surface group, the associated anomalies are shown in the scroll-down menu. 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.

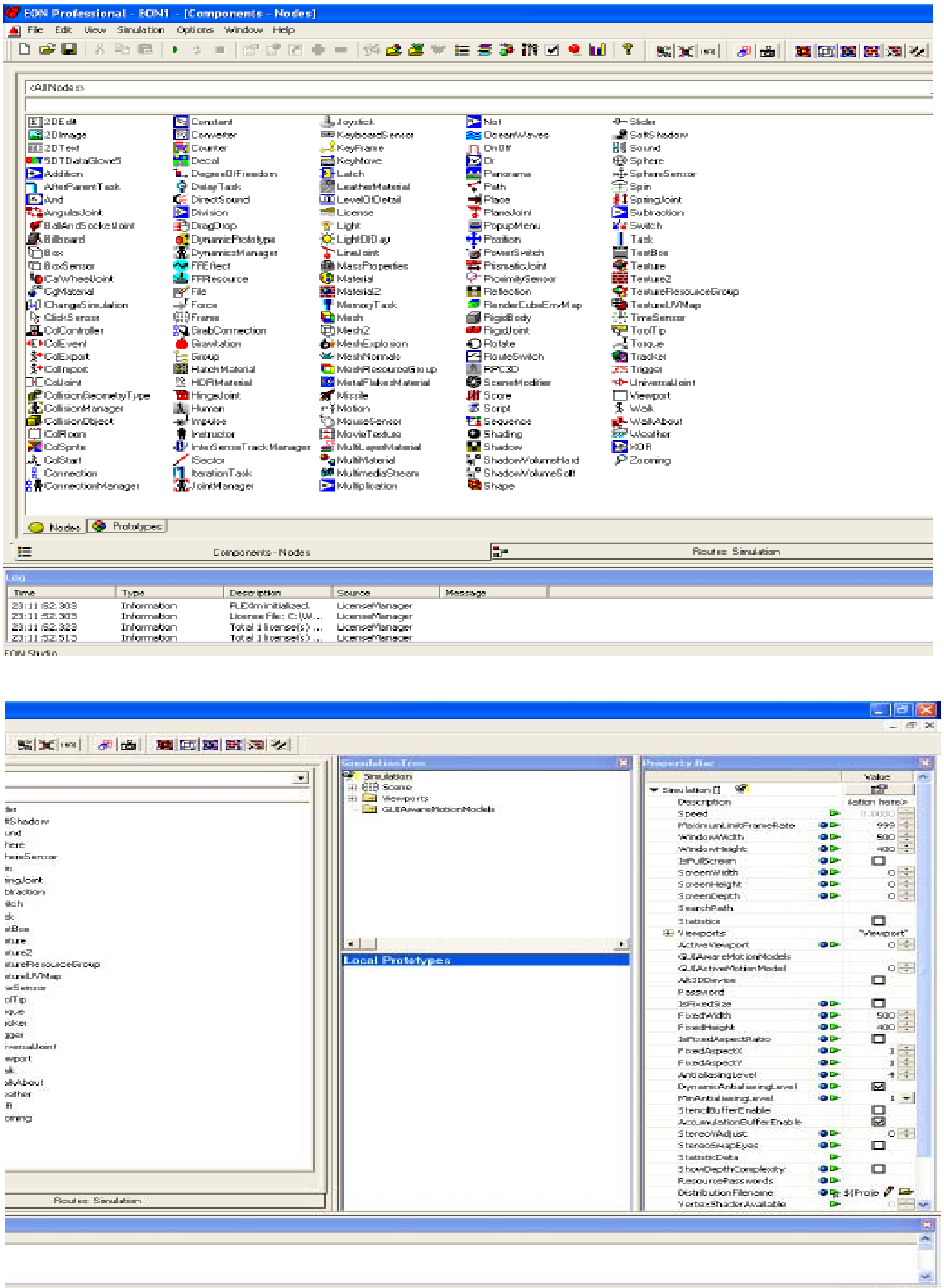


Figure 3. The EON studio interface

Anomalie	Causes
Cracking of coating elements 	1. Laying the supporting structure 2. Lack of walkways on roofs 3. Placing heavy equipment on the roof 4. Excessive amount of fixations of tiles to support 5. Effect of temperature and moisture
Insufficient size of the trim 	1. Deficient execution

Element type	Intervention
Current surface	Replacement of damaged elements.
Singular covering points	Element removal and placement of new trim with higher heights.

Table 1. Anomalies Associated to Respective Causes and Recommended Interventions

The severity of the anomaly can be characterized according to three parameters (low, medium and high), reflecting the previously realized study. The value shown in this field is then used in the element's color change in the virtual model, through the emission of information to EON, altering itself according to the severity of the anomaly, green for low, yellow for medium and red for high (Figure 5).The inspection chart interface also comprises a photo insertion zone, thus it is possible to add photographs taken in the inspection location or other images related to the element being analyzed, forming a considerably relevant complementary information for the subsequent study of repair/maintenance relative to the observed severity.

The user of this application can conduct inspections at any time, access the registered information and the virtual model and, thus, supported by the historical, define adequate plan for the roof maintenance or reparation work. 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, allowed by the application. Since the application is based on clear 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 easier analysis of the inspection data.

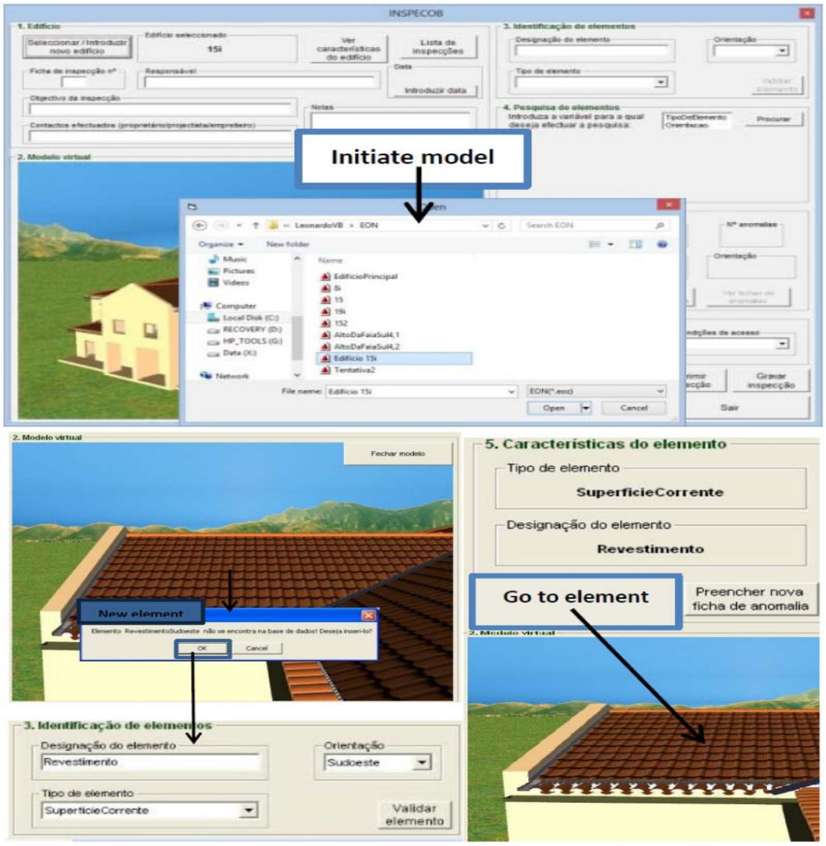


Figure 4. The VR model of roofs interface

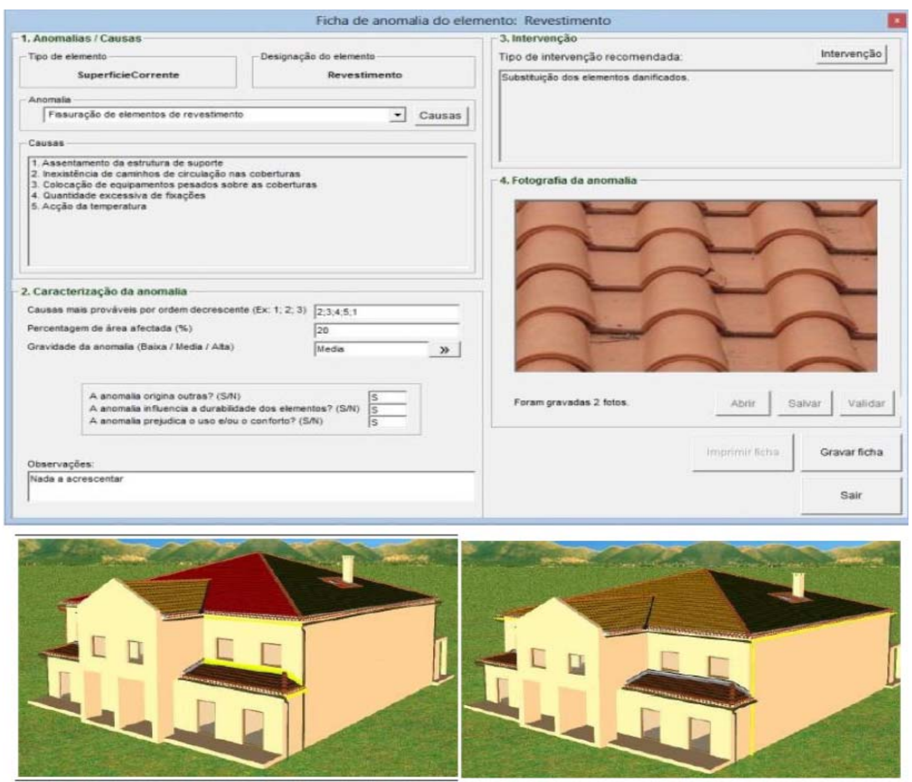


Figure 5. The anomaly chart interface and color alteration of elements

2.2 The VR Model of Façades

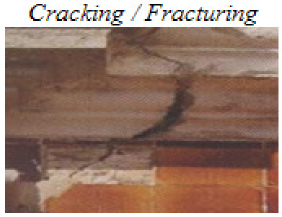
The façades VR model allows interaction with the 3D geometric model of a building, visualizing components for each construction [4]. It is linked to a database (Table II) of the corresponding technical information concerned with the maintenance of the materials used as exterior closures. The visualization of the pathology data of these exterior closure materials requires an understanding of their characteristics [8]:

• **Types of Material**: Painted surfaces, natural stone panels and ceramic wall tiles;

• **Application Processes**: Stones (panel, support devices, adherent products); ceramic tiles (fixing mechanism, procedures); painted surfaces (types of paint products, prime and paint scheme surface, exterior emulsion paints, application processes);

• **Anomalies**: Dust and dirt, lasting lotus leaf effect, covering power, insufficient resistance to air permeability or weatherproof isolation, damaged stones or ceramic tiles, alkali and smear effect, efflorescence, fractures and fissures;

• **Repair Works**: Surface cleaning, wire truss reinforcing, cleaning and pointing of stonework joints, removing and replacement of ceramic wall tiles, removing damaged paint and paint surface, preparing and refinishing stone panels.

Anomaly	Specification of the anomaly
Detachment 	Fall in areas with deterioration of support
Cracking / Fracturing 	Failure of the support (wide cracks with well-defined orientation)

Repair solution	Repair methodology
Replacement of the coat (with use of a repair stand as necessary)	1º Removal of the tiles by cutting grinder with the aid of a hammer and chisel; 2º Timely repair of the support in areas where the detachment includes material constituent with it; 3º Digitizing layer of settlement; 4º Re-settlement layer and the tiles.
Replacement of the coat (with repair of cracks in the support)	1º Removal of the tiles by cutting grinder; 2º Removal of material adjustment in the environment and along the joint; 3º Repair of cracks, clogging with adhesive material (mastic); 4º Settlement layer made with cement in two layers interspersed with glass fibre; 5º Re-settlement layer and the tiles.

Table 2. Anomalies In Facades and Associated Repair Solutions And Methodologies

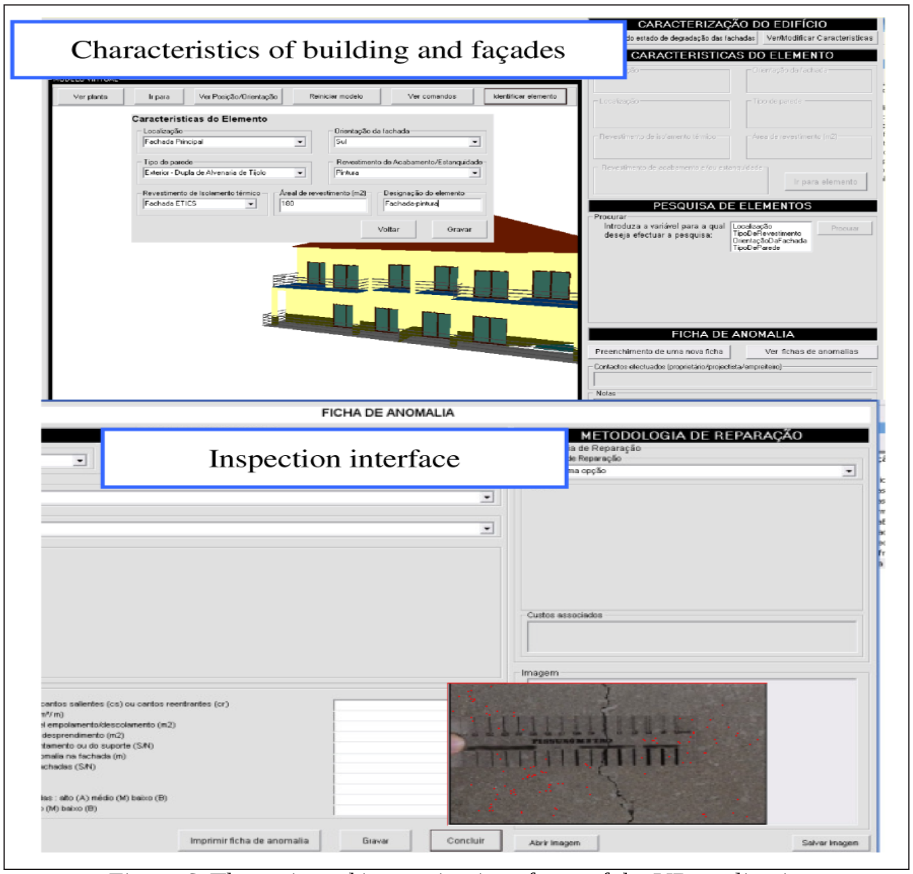


Figure 6. The main and inspection interfaces of the VR application.

The VR model interface is composed of a display window allowing users to interact with the virtual model, and a set of buttons for inputting data and displaying results (figure 6). For each new building to be monitored the characteristics of the environment (exposure to rain and sea) and the identification of each element of the façades must be defined (façade orientation, double or single exterior wall, and area and type of coating).

Once each monitored element has been characterized, several inspection reports can be defined and recorded and thereafter consulted when needed. An inspection sheet (Figure 6) is accessed by the main interface.

Using the drop-down menus of the interface, the user can associate the characteristics of the observed anomaly to a façade element; the type of anomaly, the specification, details and the probable cause of the anomaly, an adequate repair solution and pictures taken in the building. After completing all fields relating to an anomaly, the user can present the report as a *pdf* file.

The developed software is easy to handle and transport for on- site inspections and comprises information of the causes, solutions and methods for repairing. As the 3D model is linked to a database in an interactive environment and has a friendly interface to deal with this knowledge, it allows a collaborative system. With this application the user may fully interact with the program referring to the virtual model at any stage of the maintenance process and analyze the best solution for repair work. It can also support the planning of maintenance strategies.

2.3 The VR Model of Painted Walls

The material most frequently used in the coating of ordinary interior walls of buildings is paint. The durability of the painted coating depends on the environment in which it is used, and on the surface it is applied to as well as the rate of deterioration of the binder in the paint. Irregularities manifest themselves in various ways and in different degrees of severity. According to Coias [9], in normal conditions of exposure and when correctly applied a paint coating can remain unaltered for about five years. Based on the study made of the causes of the anomalies, specific methodologies for their resolution were established.

The developed VR application supports on-site inspections and the on-going analysis of the evolution of the degree of deterioration of the coating [5]. The VR model identifies each interior wall surface, in each of the rooms of the house, as independent elements. The application is supported by a database, composed by the most common irregularities (Figure 7), their probable causes and suitable repair processes, which facilitate the inspection process (Table 2).

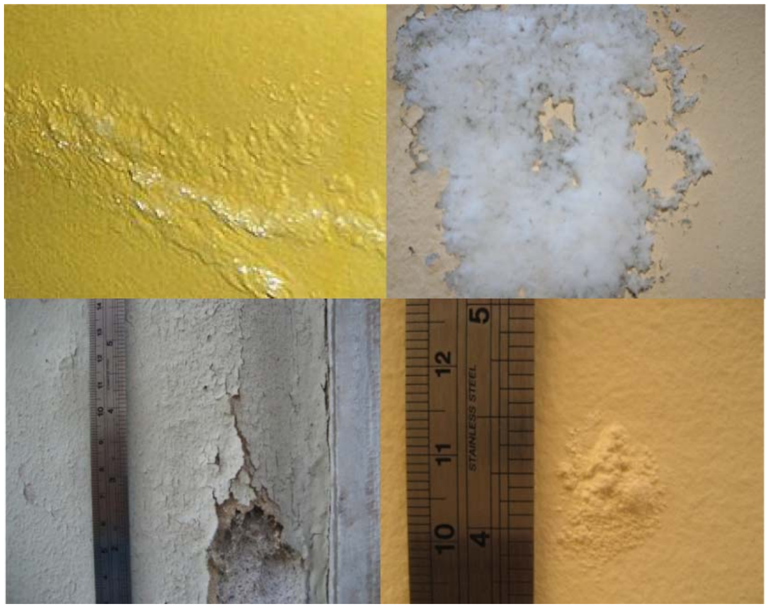


Figure 7. Common defects in painted interior walls: swelling, efflorescence, cracking and blistering

Classification	Anomalies	Repair methodology
Alteration in colour	Yellowing	- Cleaning the surface and repainting with a finish both compatible with the existing coat and resistant to the prevailing conditions of exposure in its environment
	Bronzing	
	Fading	
	Spotting	
	Loss of gloss	
	Loss of hiding power	
Deposits	Dirt pick-up and retention	- Cleaning the surface.
	Viscosity	
Changes in texture	Efflorescence	- Removal by brushing scraping or washing; - repainting the surface; - When necessary apply sealer before repainting.
	Sweating	
	Cracking	
	Chalking	
	Saponification	
Reduction in adhesion	Peeling	- Proceed by totally or partially removing the coat of paint; - Check the condition of the base and proceed with its repair where necessary; - Prepare the base of the paint work.
	Flaking	
	Swelling	

Table 3. Anomalies And Associated Repair Methodology

In addition, the model assigns a color to each of the coating elements, the colors defined by the time variable, so that the evolution of the deterioration of the coating material is clearly shown through the alteration in color. The main interface of the application gives access to the inspection and maintenance modules (Figure 8).

On an on-site inspection visit, the element to be analyzed it selected interactively on the virtual model and using the inspection interface, the specialist can select the irregularity included in the list of the database, which corresponds to the observed defect, and can select also the probable cause and the prescribed repair methodology (Figure 8). The inspection data is recorded and associated to each monitored element, allowing subsequently, the planning of repair works, thus providing a tool for the definition of a rehabilitation strategy.

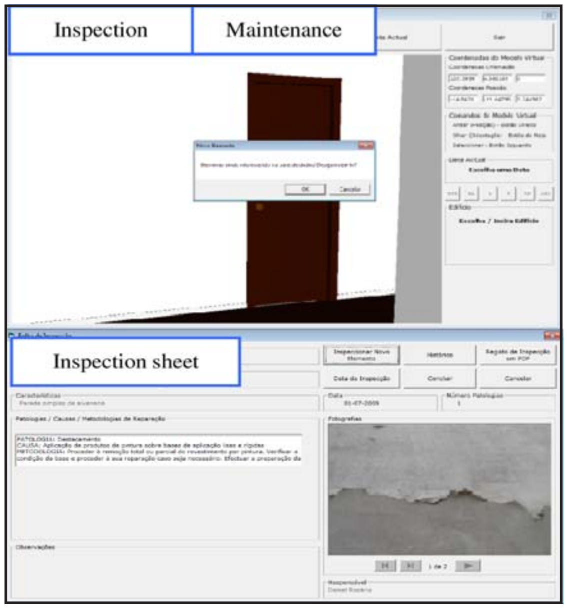


Figure 8. The main interface of the virtual application and an inspection sheet

The VR application allows the user to monitor the evolution of wear and tear on the paint coating in a house. For this, technical information relative to the reference for the paint used, its durability and the date of its most recent application must be added to each element through the maintenance interface (also accessed from the main interface, Figure 8). The period of time between the date indicated to examine the building and the date when the paint was applied is compared to the duration advised for repainting (Figure 9).

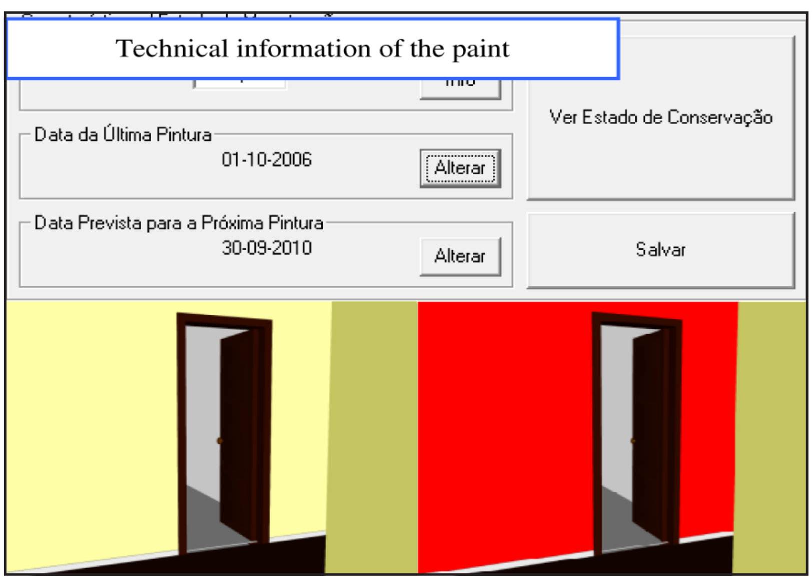


Figure 9. Chromatic alteration of the coating according to its state of deterioration

The value given for this comparison is associated to the Red, Green, Blue (RGB) parameters which define the color used for wall in the virtual model, from pale green (color referring to the date of painting) to red (indicates that the date the model was consulted coincides with that advised for repainting, Figure 9).

3. Conclusions

The presented VR applications support the inspection activity of roofs, facades and painted interior walls and promote the use of IT tools with advanced graphic and interactive capabilities in order to facilitate and expedite the maintenance process. The VR capacity of chromatic alteration was applied in two of the models allowing users to see, in the virtual environment, the state of gravity of anomalies or conservation of the coating materials.

The information about pathologies, causes and repair methods, collected from a specialized bibliography, has been organized in such a way as to establish each model database to be used as a base for the drawing up of a tool to support building maintenance. The main aim of the applications is to facilitate maintenance enabling the rapid and easy identification of irregularities, as well as the possible prediction of their occurrence through the available inspection record. This analysis has been shown as playing an important role in conservation and in the reduction of costs related to the wear and tear of buildings and contributes to the better management of buildings where maintenance is concerned.

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