Monitoring of Interior Wall Maintenance using Virtual Reality Technology

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Abstract—**In a building, the paint coating applied to interior walls conveys their aesthetic character and also performs an important function of protection. It is a construction component which is exposed to agents of deterioration related to its use, needing the regular evaluation of its state of repair. The proposed advanced computational model supports the performance of such periodic inspections and the monitoring of interior wall maintenance, using Virtual Reality (VR) Technology. Used in an inspection visit the application allows users to consult a database of irregularities, normally associated with paint coating, classified by the most probable causes and by recommended repair methodologies. In addition, with this model, a chromatic scale related to the degree of deterioration of the coating, defined as a function of the time between the dates of the application of the paint and the scheduled repainting, can be attributed to each element of coating monitored. The use of VR technology allows inspections and the evaluation of the degree of wear and tear of materials to be carried out in a highly direct and intuitive manner. The developed computer application is an advanced computation tool with innovative visualization and interactive capacities, and so brings a positive contribution on the construction field.**

Keywords- Information Technology; Virtual Reality; Building Maintenance.

I. INTRODUCTION

The coating applied to building walls, naturally, performs an important aesthetic function: it is, however, essentially a protective element for the substrate on which it is applied as far as the action of environmental agents of wear and tear is concerned. The coating is fundamental to a proper overall performance of a building throughout its working life.

Materials frequently used in the coating of ordinary buildings are paint, varnish, stone and ceramics [1]. In Portugal, where interior walls are concerned, the most commonly used coating is paint. It is a multi-purpose material, used under a variety of decorative effects, based on a widely-ranging palette of colors, patterns and textures and is easily applied on any type of surface. In addition, paint, compared to other materials, is less costly; not only as far as the product

itself is concerned, but also in its application, since relatively non-specialized labor is required. Nevertheless, as deterioration is a given, maintenance is needed.

Factors such as the constant exposure of the coating 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 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. 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 exposure and when correctly applied, a paint coating can remain unaltered for about five years. 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 suitable 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 of 4D models (3D + time) through which the evolution of deterioration can be visually demonstrated and understood. Furthermore, the possibility of interaction with the geometric models can be provided through the use of Virtual Reality (VR) technology. The developed VR/4D model is an advanced computer tool in the maintenance field.

The work presented here is part of an on-going research project: Virtual Reality technology applied as a support tool to the planning of construction maintenance. PTDC/ECM/ 67748/2006 [3] and as such is a component of the Project focusing on the support of the maintenance activity planning with particular reference to paint coating applied to interior walls of buildings for housing.

The completed computer virtual model identifies the elements of the building which make up the interior wall coating so that monitoring can take place. The application is supported by a database, created for the purpose, of irregularities, their probable causes and suitable repair processes, which facilitates the inspection process. The information is recorded and associated to each monitored element, allowing subsequently, the inspection and repair activity log to be consulted, thus providing a tool for the definition of a rehabilitation strategy. 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 prototype is, then, a 4D model.

The model integrates a virtual environment with an application developed in Visual Basic programming language. This allows interaction with the 3D model of buildings in such a way that it becomes possible to follow the process of monitoring the coating elements, specifically, painted interior walls, in terms of maintenance, throughout the life-cycle of the building. Advantages of 4D virtual environments are found in improving communication, increasing insight, supporting collaboration, and supporting decision-making. Namely Fumarola and Poelman [4] discuss different approaches on the generation of virtual environments of real world facilities supporting decision-making.

The development of several applications, have been successfully implanted, in different branches of construction and education domain. The requisites of the real environment can be illustrated by the different VR models developed within the research project: The implemented virtual prototypes concern the management of a lighting system in a building [5], the construction activity [6] and the maintenance of building façades [7]. Figure 1 illustrates the two last VR models.
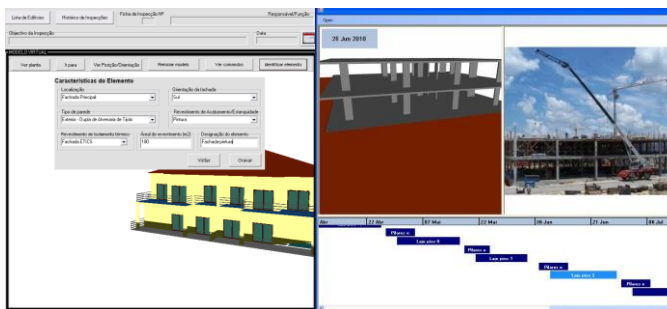

Figure 1.   VR models of maintenance and construction activity.

The research project follows a previous work related to the development didactic VR models regarding construction processes: the construction of a wall (Figure 2), a roof [8] and bridge decks using two different methods (Figure 3), the cantilever process [9] and the incremental launching method [10].

When comparing the present computer model with the previous work, the principal innovation concerns the incorporation of the capacity of changing the color of the painted wall with the time parameter, when walking-through

the virtual model. So the evolution of the deterioration of the coating material is visualized through the alteration in color.
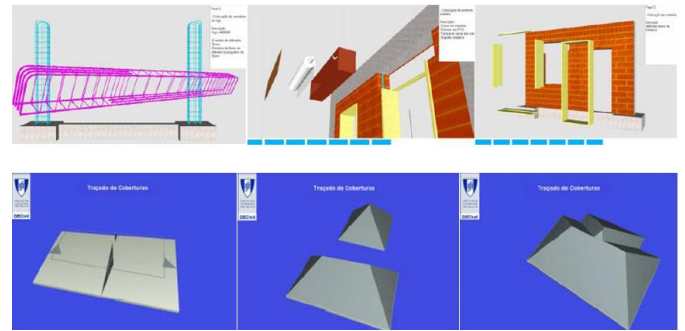

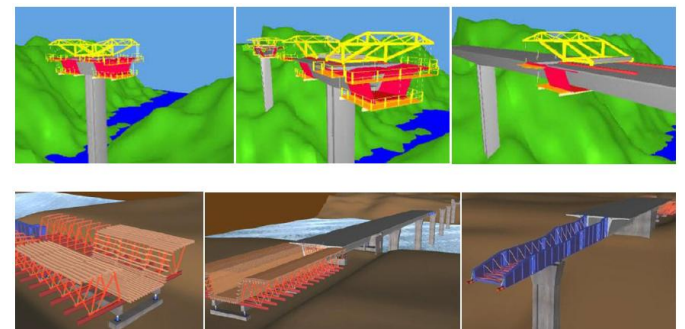Figure 2.   VR models of the construction of a wall and a roof.

Figure 3.   VR models of construction of bridge decks.

The paper presents the main aspects of a VR application concerning the maintenance of buildings [11] with a focus on inspection of painted walls. Then the anomalies that most often originate in the painted finish, which are listed in an identical manner to that used in the virtual model database. The text describes how to interact with the virtual model on the conduct of inspections and monitoring of wall elements. Finally it makes a comparison with the traditional way of performing and points out the major benefits in the use of the interactive computational tool of maintenance support.

II.   MAINTENANCE

The General Regulations for Urban Buildings (RGEU) a decree-law from 1951 [12] stipulates the frequency of maintenance work, stating that existing buildings must be repaired and undergo maintenance at least once every eight years with the aim of eliminating defects arising from normal wear and tear and to maintain them in good usable condition in all aspects of housing use referred to in that document. The time-limit indicated is applicable to all elements of the buildings generally. It is clear, however, that the regulatory period is too long for some specific components and that, frequently enough, the time-limits for action are not respected. There are, too, inefficient rent policies, leading to long periods without rehabilitation, and that the prevailing culture is one of reaction on the part of the various parties involved in the maintenance process. To these aspects should also be added the defects sometimes registered during the construction of

property developments, exacerbating the poor state of repair of the buildings. This gives rise to numerous irregularities which, in turn, frequently leads to inadequate safety conditions.

According to Cóias [13] the purpose of maintenance is to prolong the useful life of the building and to encourage adherence to the demands of safety and functionality, keeping in mind the specific set of conditions of each case and its budgetary considerations. Satisfactory management of this activity is carried out by putting into practice a maintenance plan which must take into consideration technical, economic, and functional aspects arising with each case. Collen [14] points out that investment in the maintenance and rehabilitation sector in Portugal is still weak compared to that in the same sector in the construction industry in the other countries of the European Community. She makes it clear, however, on a more positive note, that some measures have already begun to be implemented here: some urban regeneration programs have been created, legislation, which focuses on the sustainability of buildings, has been laid down, and the revision of constructive solutions has been carried out, all with the objective of guaranteeing that the maintenance of built heritage be an integral part of the construction sector.

The maintenance of buildings, then, is an activity of considerable importance within the construction industry; its contributory aspects of conservation and rehabilitation work need to be supported by correct methodologies of action, underpinned by scientific criteria and by suitable processes for the diagnosis of irregularities and the evaluation of their causes. This paper aims to make a positive contribution to this field using the new computer technology tools of visualization and interaction.

III. PATHOLOGIES IN PAINT COATINGS

The technical document Paints, Varnishes and Painted Coatings for Civil Construction published by The National Laboratory for Civil Engineering (LNEC), defines paint as a mixture essentially made up of pigments, binder, vehicle and additives [1]. It has a pigmented, pasty composition, and when applied in a fine layer to a surface, presents, after the dispersion of volatile products, the appearance of a solid, colored and opaque film [15].

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. The influence of the environment is the result of the action, in conjunction or alone, of a variety of factors such as the degree of humidity, the levels of ultraviolet radiation, oxygen, ozone and alkalis, variations in temperature and of other physical or chemical agents whose effect depends considerably on the time taken to apply it [16]. When their influence is not counteracted or minimized, imperfections can arise in the coating film, such as, the appearance of defects in the layer or paint with the loss of functionality where the desired aim of the application is concerned. These irregularities manifest themselves in various ways and in different degrees of severity.

Based on the study made of the causes of the defects, specific methodologies for their resolution were established. Figure 4 shows common defects in painted interior walls. The information gained from the pathological analysis of this type of coating was used to draw up a database supporting the interactive application.
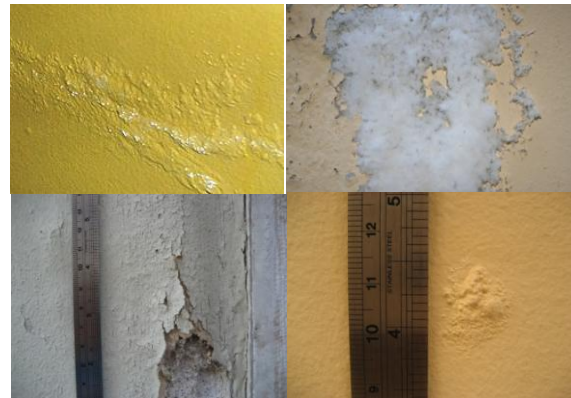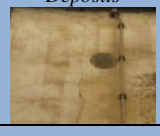

Figure 4. Swelling, efflorescence, cracking and blistering [17].

These data support the creation of inspection files related to the elements which are monitored in each case studied. In order to form a user-friendly database of relatable data, groups of pathologies, shown below in Table I, were considered. This classification provides the required automatism of access to the database and supports the presentation of synopses of the causes and repair methodology inherent in each pathology.

TABLE I. CLASSIFICATION OF IRREGULARITIES.

Classification	Irregularity	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;
	Flaking	

	Swelling	- Prepare the base of the paint work.

During the process of an on-site inspection, the user of the application can refer to the database in order to classify the abnormality being observed, consulting the list of defects, which includes, in addition to their identification, the most relevant characteristics and some of the causes that could be at the root of their development. Table II lists two of the irregularities from the classification: *Alteration in color*.

TABLE II.   IRREGULARITIES AND CAUSES.

Classification	Irregularity	Characteristics and causes
Alteration in colour	Yellowing	- A yellow colour caused by ageing of the film of the paint or varnish; - Action of environmental agents (solar radiation, temperature oxygen and humidity) on the binder in the paint provoking changes in its molecular structure.
	Discolouration	- Partial loss of colour of the film of paint coating; - Action of environmental agents (solar radiation, temperature, polluted atmosphere and chemically aggressive bases of application) on the binder and/or the pigments of the painted coating.

The database was created with adequate relations between data, concerning each group of anomalies, in order to present the sequence of anomaly, provable cause and adequate repair work, to the engineer when it uses the virtual model in an inspection situation. The specialist must choose in each case the most appropriate sequence.

IV.   INTERACTIVE MODEL

The completed application supports on-site inspections and the on-going analysis of the evolution of the degree of deterioration of the coating [11]. The following computational systems were used in its development:

- AutoCAD, in the creation of the 3D model of the building (based on the drawings presented in Figure 5);

- EON studio for the programming of the interactivity capacities integrated with the geometric model (Figure 6 shows the main interface);

- Visual Basic 6 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.

The scheme of links between software is presented in Figure 7. All the systems were made available by the ISTAR/DECivil informatics laboratory of the Technical University of Lisbon. The main interface of the application gives access to the virtual model of the building and to the inspection and maintenance modules (highlighted in Figure 8).
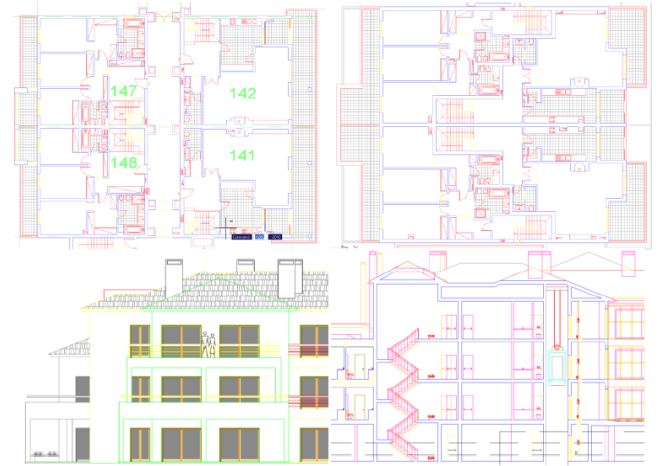

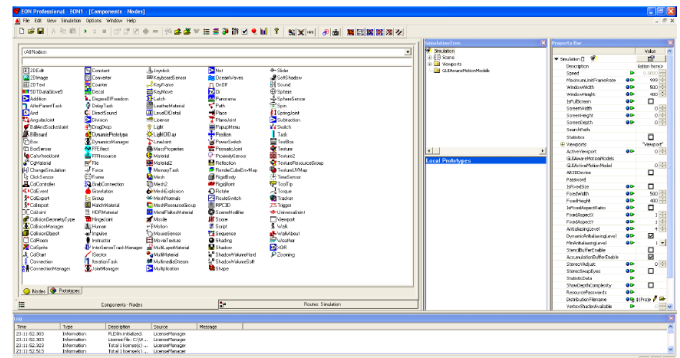Figure 5.   Technical drawings of the building.
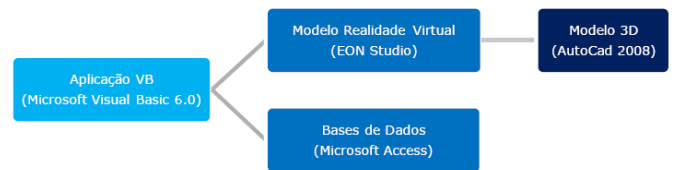

Figure 6.   The EON studio interface.

Figure 7.   Scheme of links between software.

The first step is to make a detailed description of the building (location, year of construction, type of structure, etc.) and representative modeled elements of the interior wall coating, so that they can be monitored. The model is manipulated in the virtual environment by using the mouse buttons (movement through the interior of the model and orientation of the camera). The coordinates of the observer's position and the direction of his/her point of view are associated with the element during the process of identification. Thus, later, when an element in the database of the application

is selected using the interface, the model is displayed in the visualization window so that the target coating can be observed.
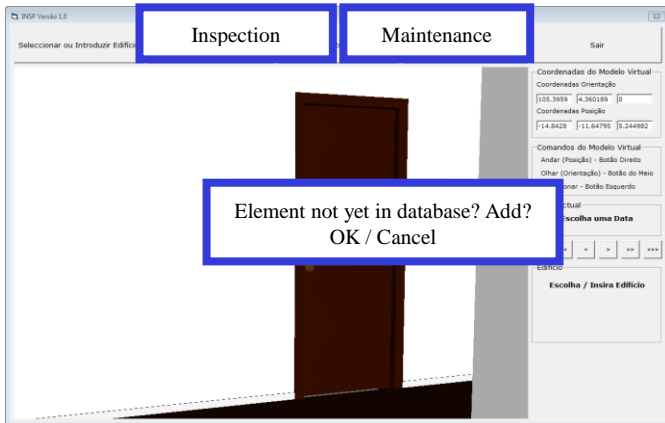

Figure 8.   The main interface of the virtual application.

Walking through the model with the aim of accessing all the elements of the building, the user needs to be able to go up and down stairs or open doors or windows.

The virtual model has been programmed, using the EON system, in such a way that these capacities are activated by positioning the cursor over the respective objects, in that way, the user is able to walk through the whole model. Each wall surface in each of the rooms of the house is a component which has to be monitored and, therefore, to be identified. Using the model, the user must click the mouse on an element, and the message *New Element* is shown (highlighted in Figure 8). Associated to this selected element is the information regarding location within the house (room, hall, and bedroom), wall type (simple internal masonry wall, and double exterior wall) and coating (paint, tile, and natural stone).

A.   Making an Inspection

Later, on an on-site inspection visit, the element to be analyzed it selected interactively on the virtual model. The inspection sheet interface is accessed by using the *Inspection* button which is found in the main interface (Figure 8). The data which identify the selected element are transferred to the initial data boxes on the displayed page (Figure 9).

Figure 9.   Identification of the selected element.

Next, using the database, the irregularity which corresponds to the observed defect, with its probable cause (*ageing*) and the prescribed repair methodology (*removal and repainting*) is selected (see highlighted area, Figure 10). The current size of the pathology should also be indicated since it reveals how serious it is (*area of pathology*, Figure 10).

Figure 10. Interface for the selection of the irregularity, probable cause, area and repair methodology.

In the field *Observations*, the inspector can add any relevant comment (Figure 10), photographs obtained on site can also be inserted into the inspection window and the date of the on-site visit and the ID of the inspector should also be added. Several different irregularities in the same coating can be analyzed (field *Number of pathologies*, Figure 11) and other elements can be analyzed and recorded and defects observed.

Figure 11. Presentation of the information introduced into the inspection sheet.

Later, the files thus created, associated to each of the virtual model elements, can be consulted (*Case History* button in the *Interface* in Figure 11). This same window allows all the data referring to the building and to the completed inspection to be shown, as an inspection report in *pdf* format (Figure 12).

Inspection report

| Ficheiro | Insp_DuplexCascais_01_10_2011 | Data de Inspecção | 01-10-2011 |

Dados do Edifício

Building data
Year built: 2000
Location: Cascais, Portugal
Type of use: housing

Dados do Elemento

Element details
Location: Hall 1
Type of wall: Interior
Description details: Simple masonry wall

Patologias / Causas / Metodologias de Reparação

PATOLOGIA: Destacamento

Pathologies/Causes/ Repair Methodologies
Pathology: Peeling
Cause: Natural ageing of paint coating
Repair methodology: Total or partial removal of paint coating.

Figure 12. Inspection report.

B. Maintenance Monitoring

How long the working life of any construction component might be is an estimate and depends on a set of modifying factors related to their inherent characteristics of quality, to the environment in which the building is set and to its conditions of use [13]. In maintenance strategy planning the probable dates when adverse effects might occur in each of these elements must be foreseen, and the factors which contribute to defects must be reduced and their consequences minimized.

The VR model 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 (Figure 13) to each element through the *Maintenance Interface* (also accessed from the main interface, Figure 8). Based on these data, it is possible to link in the date the virtual model is consulted and visualize, in the geometric model, the level of wear and tear as a function of time (see *state of painting*, Figure 13).

The period of time between the date indicated and the date when the paint was applied is compared to the duration advised, in the technical literature, for repainting. 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.

Technical and commercial characteristics

Marca
Tintas e Companhia - Tinta acetinada - Branca - REF. 000000

Tipo
Interior

Localização
Hall1

Características / Estado de Manutenção
Durabilidade
4 Anos   Info

State of the painting

Data da Última Pintura
01-10-2006   Alterar

Data Prevista para a Próxima Pintura
30-09-2010   Alterar   Salvar

Figure 13. Technical characteristics and the durability of the paint-work.

In this way, the color visualized on the monitored wall varies according to the period of time calculated, pale green being the color referring to the date of painting and red indicating that the date the model was consulted coincides with that advised for repainting (Figure 14).
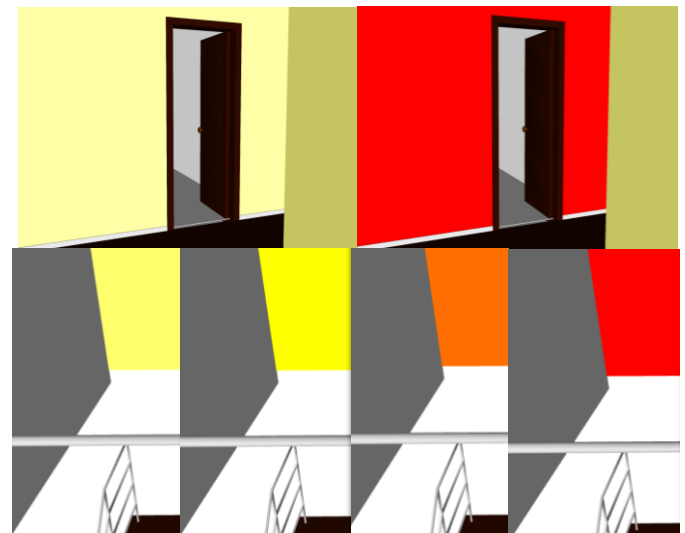

Figure 14. Chromatic alteration of the coating according to its state of deterioration.

The date for painting and repainting are saved to a list of coating elements to be monitored in the virtual model. When an element is selected from this list, the corresponding element is represented in the virtual model, through the preview window, in the color that corresponds to the period of the consultation (Figure 13).

Later, when walking-through the house, the walls feature the color corresponding to the date of visualization of the virtual model. The degree of deterioration of painted coating is thus more intuitive for the user. If the walls present a color

close to red, these walls must be repainted quickly. Based on this observation the engineer sets an appropriate planning to repaint the entire house or part of it. Repainting work should be supported, not only on the date of repainting, but also with the analysis for the inspection data concerning the anomalies observed in the building. Based on all the surveyed information, the engineer must establish a suitable repair plan.

C. Principal innovations and benefits

Normally, the inspection process of buildings is based on filling out paper files during the site survey. The inspector shall observe and analyze the anomalies observed, sort them and add comments that are timely, related to the degree of deterioration, so that, later, to establish a global repair work plan for the building. With the use of computer system supported on the basis of data relating to the maintenance of the interior wall paint coating, the inspector shall select among the possibilities listed, the anomaly, possible cause and repair methodology that seems more appropriate. Moreover you can add photos. The definition of the repair plan is based on the analysis of the data entered and selected in the system. The designer must establish on the basis of the needs and economic availability of a proper maintenance plan, encompassing the various anomalies observed. The computer system allows registration, during the inspection, deficiencies and their seriousness, by supporting the planning of repair work.

The inspection process requires one or more visits to the site of the building [15]. There are made several observations which are annotated in sheets of paper. Based on these notes is elaborated a rehabilitation draft to the building. With the support of developed computer system the inspector can easily associate to the 3D model of the building the identification of the anomalies, know its extent and severity. The facility to incorporate photos from local helps assess the severity of repair work to be carried out later. The main innovation in the use of the model is to allow the designer to move within a virtual mode through the interior of the model, know the location, type and severity of each anomaly in relation to each wall area. In this way the designer can more easily analyze the global repair strategy. For an inspection based on paper there is no longer a global perspective of the house inspected and therefore the study of repair work to predict is more difficult. Furthermore, the virtual model has a history of documented inspections with timely remarks, comments and photos. You can add the repair operations after intervention and thus compare the observed problems and what the resolution applied.

V. CONCLUSIONS

This application supports the maintenance of painted interior walls and promotes the use of IT tools with advanced graphic and interactive capabilities in order to facilitate and expedite the inspection process. The virtual model, moreover, allows users to see, in the virtual environment, the state of repair of the coating. The information about pathologies, causes and repair methods, collected from a specialized bibliography, has been organized in such a way as to establish a database to be used as a base for the drawing up of a tool to support building maintenance. The main aim of the application 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. Cost reduction is related to the ability of the virtual model can forward in an intuitive manner, with the visualization of changing the color of the walls in the model, with the date of visualization of the virtual model. It is thus possible to analyze whether there is need to repaint and establish a repair project, namely the repainting of the interior walls of the building.

In addition to the inspection component, a maintenance component was developed which, being visualized in a VR environment, as well as being highly intuitive, facilitates the analysis of the state of repair of buildings. By means of a chromatic scale applied to the monitored elements, displayed in the walk-through of the geometrically modeled building, it is possible to identify the elements which, predictably, will need timely action. With the possibility of altering the time parameter freely, the user can carry out this analysis either for past instants or for future events, being able, in this way, to forecast future operations. This capacity of the model, therefore, contributes to the avoidance of costs associated to irregularities which, with the passage of time, become more serious and therefore more onerous.

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