Maintenance and Inspection of Façades of Building Supported on Virtual Reality Technology

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Abstract. *A Virtual Reality model was created in order to help in the maintenance of exterior closures of walls in a building. It allows the visual and interactive transmission of information related to the physical behavior of the elements, defined as a function of the time variable. To this end, the basic knowledge of material most often used in façades, anomaly surveillance, techniques of rehabilitation, and inspection planning were studied. This information was included in a data base that supports the periodic inspection needed in a program of preventive maintenance. The results are obtained interactively and visualized in the virtual environment itself. This work brings an innovative contribution to the field of maintenance supported by emergent technology.*
Keywords. *Virtual Reality; Maintenance; Interaction human-machine.*

INTRODUCTION

The main aim of a research project, now in progress at the Department of Civil Engineering of the Technical University of Lisbon, is to develop virtual models as tools to support decision making in the planning of construction management and maintenance. A first prototype concerning the lighting system has already been completed (Sampaio et al., 2009). A second prototype concerning the maintenance of the closure of walls interior, is now being developed. This paper describes another prototype concerning the maintenance and inspection of façades.

The interactive model integrates Virtual Reality (VR) technology, the EON system (2010), and an application implemented in Visual Basic (VB) language. The model allows interaction with the 3D geometric model of a building, visualizing components for each construction. It is linked to a database of the corresponding technical information concerned with the maintenance of the materials used as exterior closures. The principal objective of the interactive VR prototype is to support decision-making in the maintenance domain.

The present project aims to bring important contributions to this domain, through the implementation of virtual models able to relating the behavior of materials, their characteristics, anomalies and repair work to each other. During this work the basic knowledge of the topics involved, such as aspects 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 model are explored.

The prototype for walls was trialed in a concrete project. This kind of building element 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 model facilitates the visual and interactive access to results, supporting the definition of inspection reports. It will be possible in the future to apply this to other building situations whether in new constructions or those needing rehabilitation.

INTERACTIVE AND COLLABORATIVE MODELS

Virtual Reality technology can support the management of data that is normally generated and transformed or replaced throughout the lifecycle of a building. This technology becomes an important support in the management of buildings allowing interaction and data visualization. At present, the management of building planning can be presented in a 3D form and various materials can be assigned to the fixtures and furnishing enabling the user to be placed in the virtual building and view it from inside as well as outside. This study contemplates the incorporation of the 4th dimension, that is, time, into the concept of visualization. The focus of the work is on travelling through time: the ability to view a product or its components at different points in time throughout their life. It is envisaged that the incorporation of the time dimension into 3D visualization will enable the designer/user to make more objective decisions about the choice of the constituent components of the building. In maintenance the time variable is related to the progressive deterioration of the materials throughout the building's lifecycle.

The present prototype incorporates interactive techniques and input devices to perform visual exploration tasks. To support this system a data base was created which included a bibliographic research support made in regard to the closure materials used in the 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 3D model linked to a data base concerning maintenance produces a collaborative virtual environment, that is, one that can be manipulated by partners interested in creating, transforming and analyzing data in order to obtain results and to make decisions. For example, inspection reports can be defined and consulted by different collaborators. The process of developing the prototype interface considers these purposes. The developed prototype associates the characteristics of the coating component of the exterior walls to activities concerning the maintenance of buildings (Figure 1).

WALL MAINTENANCE PROTOTYPE

Façade coatings play an important 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. Naturally, they should also give the façade the required decorative effect. Since this building component is exposed to bad atmospheric conditions it frequently shows an evident degree of deterioration, requiring maintenance

Figure 1
3D model of the house: coating elements of exterior walls.

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.

In order to better understand the operation of façade coating, bibliographic research of materials usually applied to façade coatings was carried out and a table of characteristics of these was drawn up. Subsequently, a survey was made of anomalies, probable causes, solutions and methods of repair for each of the coatings studied.

The visualization of the maintenance data of a building and the impact of time on the performance of these exterior closure materials require an understanding of their characteristics (Gomes and Pinto, 2009) (Figure 2):

- 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, ...

Characteristics of the materials used in façades

Depending on the role that the façade coatings play on the wall as a whole they can be classified as finishing, sealing or thermal insulation. The most frequent materials used as coating finishes are painting, tiling and, as sealing coating of the natural stone:

- Paint coating contributes to the aesthetic quality of the building and its environment and also protects the surface of the exterior wall against corrosion, deterioration and penetration of aggressive agents (Lopes, 2008). In order to obtain a good performance as an exterior coating, several aspects must be considered, such as covering power and resistance to water, sunlight, chemical products and to the development of micro organisms;
- The ceramic coating consists essentially of tiling panels, cement and adhesive and the joints between the slabs. The application of ceramic tiling to building façades has considerable advantages particularly as some degree of waterproofing is afforded by the glazed surface along with a great resistance to acids, alkalis and vapor. Other advantages are that it does not need painting and that it can be easily applied or substituted during repair work (Ferreira et al., 2009);
- The use of natural stone in the coating of façade surfaces is a good solution both technically and aesthetically. The stone coating is composed of slabs of stone attached to the wall by a support system. The principal characteristics of the stones are: reduced water absorption, sufficient mechanical resistance to bending and impact, abrasion and shearing parallel to the face of the slabs (Veiga and Malanho, 2009).

Figure 2
Different type of materials applied as façade coatings.

The database

The most frequent anomalies that occur in the coated façades were analyzed in order to create a data base linked to the virtual model that could support planning of inspections and maintenance strategies in buildings. The database contains the identification of anomalies that can be found in each type of material used in façades and the corresponding probable cause. For each kind of anomaly the most adequate repair solutions are also selected and included in the data base. The following example concerning deficiencies in tiles presents the methodology implemented in this virtual application (Table 1).

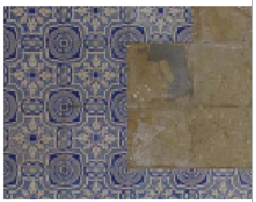
The characteristics related to anomalies, causes, repair solutions and rehabilitation tasks were included in a database of each type of material and linked to the 3D model of the building. Thus, the virtual model gives users the ability to transmit, visually and interactively, information related to the closure properties of exterior walls, allows them to analyze the anomalies observed in an inspection of the real building and to predict the corresponding repair work. The 3D virtual model can be seen, therefore, as an important tool for anomaly surveillance in structures and for supporting decision-making based on the visual analysis of alternative repair solutions.

The interface

The implementation of the prototype system makes use of graphical software programming, Visual Basic 6.0 Microsoft, software to establish an adequate database, Microsoft office access, graphical drawing system, AutoCAD Autodesk and VR technology based software, EON Studio.

Human perceptual and cognitive capabilities were taken into account when designing this visualization tool so the model is easy to use and does not require sophisticated computer skills: many potential users are not computer experts. It uses

Table 1
Example of anomalies and the associated repair solution

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

an interactive 3D visualization system based on the selection of elements directly within the virtual 3D world. Furthermore, associated with each component, there are integrated databases, allowing the consultation of the required data at any point in time. The 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 3).

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. The data associated to each element are the building orientation, the type of exterior wall (double or single), and the 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 is accessed by the main interface (Figure 4).

Using the drop-down menus allowed by the interface, the user can associate the characteristics of the observed anomaly to: a façade element; the

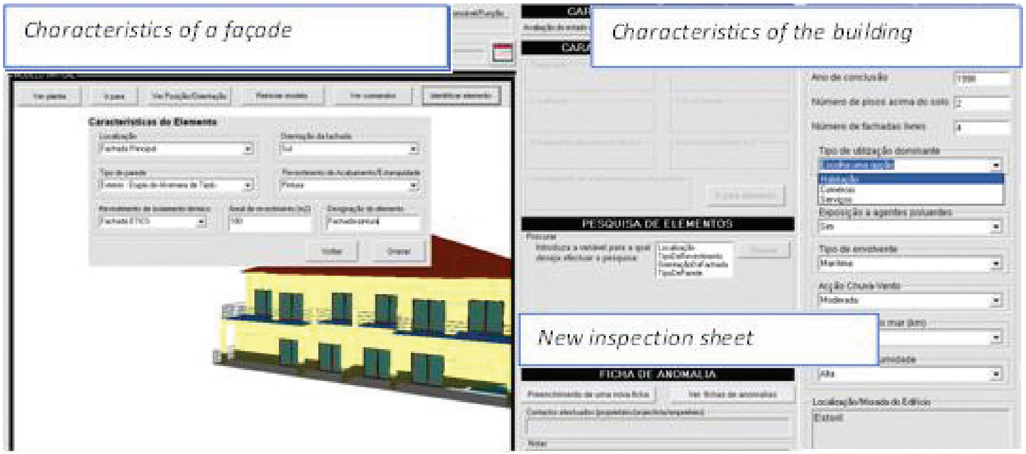


Figure 3
The main interface of the interactive application.

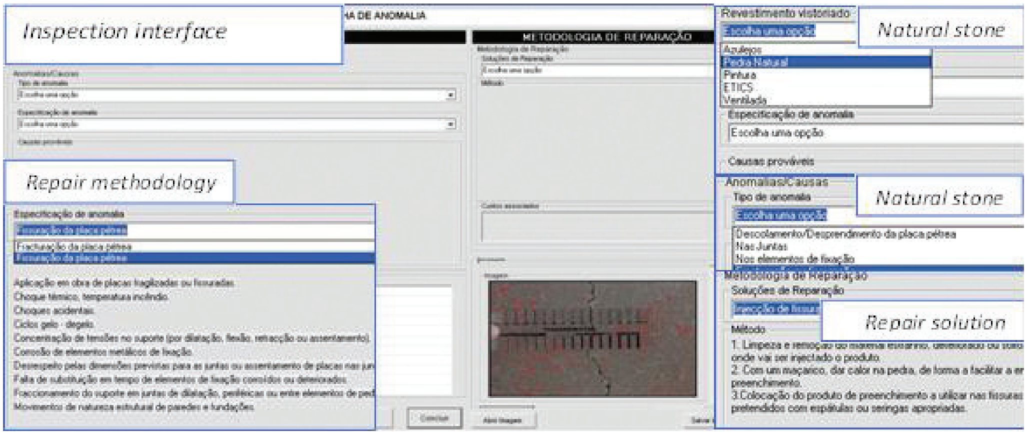


Figure 4 Inspection sheet interface.

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 case study

First, the 3D geometric model of a building case was created (Figure 5). The building consists of a ground-floor, a 1st floor and an attic with dwelling space shown. The coating elements of the walls were then modeled as independent geometric objects. In this way, each element can then support characterization data of the applied material and different kinds of information related to maintenance.

All coatings studied were considered in this case-study. Thus it was assumed that the main façade is covered with tile and the remaining façades are painted while hall façades are of natural stone. Figure 6 shows how to identify a façade in the virtual model of the building. Figure 7 includes the inspection report of the anomaly previously considered.

A VR model to support the maintenance of walls in a building was developed within a research project. It enables the visual and interactive transmission of information related to the physical behavior of the elements, defined as a function of the times variable. The model shows the characteristics of each element of the building in the model and the information related to inspection, anomalies and repair works. As the 3D model is linked to

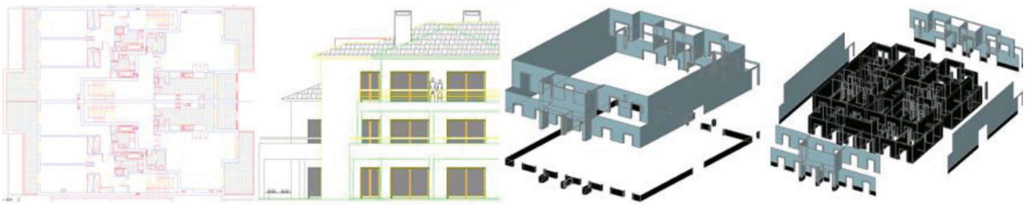


Figure 5
Steps of the geometric modeling process.

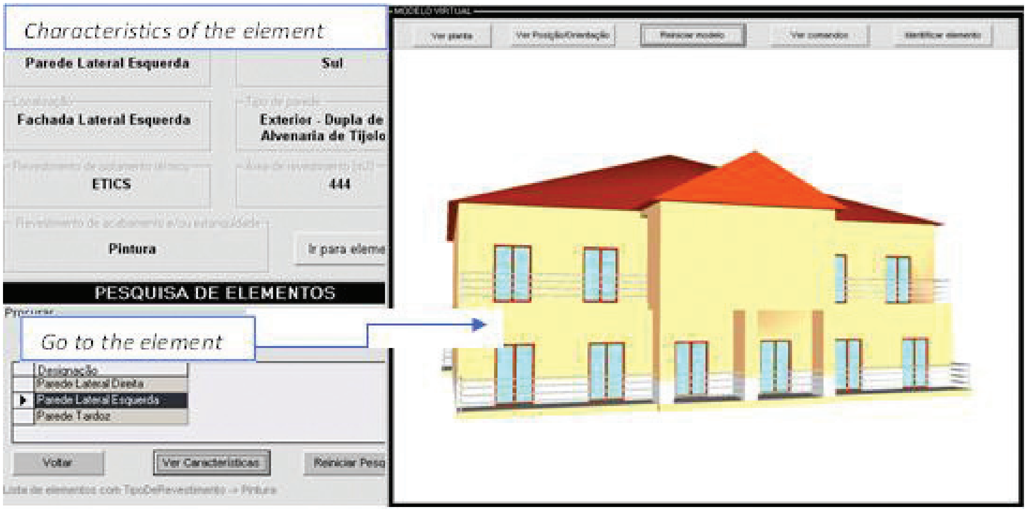


Figure 6
Identification of a façade element.

Figure 7
Inspection sheet report.
Conclusions

a data base in an interactive environment and has a friendly interface to deal with this knowledge, it allows a collaborative system. The work is still in progress. 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. The developed software is easy to handle and transport for on-site inspections and comprises information of the causes, solutions and methods for repairing.

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