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Virtual Reality Applied on Civil Engineering Education: Construction Activity Supported on Interactive Models*

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Besides the constant updating of training in the new graphic resources available to engineering and architecture professions, and in widespread and frequent use, the school should also adapt its teaching activities to the new tools of visual communication. In Civil Engineering, the capacity to visualize the construction, management and maintenance of buildings can be added through the use of three-dimensional (3D) models, which facilitate the interpretation and understanding of target elements of maintenance and construction and of 4D models (3D + time) through which the evolution of construction steps and deterioration of materials 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 text presents a new perspective of introduction an innovative technology in school. The VR technology is used as a tool to create interactive applications as a part of a research work. The students involved in this research had to learn advanced software of geometric modeling and visualization and to explore the capacities of a VR technology system. Also, programming skills had to be adapted to establish the integration needed for the creation of virtual prototypes. Moreover, the structure of different kind of databases had to be studied and implemented, integrating diverse types of information, needed to develop the interactive virtual model. The VR technology was introduced in school in order to prepare Civil Engineering students to consider this knowledge as an important support, later in professional activity, and also to facilitate the link between engineering theory and its implementation. The VR applications were developed to be used in the construction activity.

Keywords: research in education; virtual reality; construction activity; interactive model

1. Introduction

Actually, Information and Communication Technologies (ICT) have established itself as a part of the social and economic enterprises, as well as in entertainment, education, culture, etc. Educational sector has recognized these potentials and has incorporated networks and multimedia as important tools for enhancement and upgrade of learning process. At present times, the educational process includes many ICT based methods for teaching and learning [1]. So, the relevance of the use of ICT in education is quite evident nowadays. In particular, the use of ICT in teacher training has been considerably analyzed, especially in relation to learn how to use ICT as a teaching tool [2]. Exposing teachers in training to the technologies and experiences that will be important to their professional future can contribute to the development of a range of indispensable abilities for their teaching activities which are not available in a model of traditional training. It is a fact that advanced computer and information network technology can improve the quality of our teaching and learning approaches and methods and this also can changes the learning environment and the way student understand scholar issues. On higher education it helps to improve quality of the teaching learning process. Consequently, the evaluation of teachers' performance in teaching activity, supported on ICT, is especially relevant for the academic institutions. Thus, by means of the use of the ICT teachers were able to integrate different aspects that are novel in relation to traditional education, like the change and renovation in the didactic process, besides the use of new recourses, educational infrastructures and practices. Furthermore the ICT suppose a modification in the strategies and methodologies that harness the continuous learning of student, and have become an important instrument of support in the educational innovation in the last years, allowing the personalization of the learning process, centering now more in the learning of the student [3].

Computer-Aided Design (CAD) techniques can produce educational materials, likely to be used for training of future researchers and professionals in engineering subject. In addition, the interaction with the VR models helps student to better understand the diversity of the engineer activity. And students may benefit of the possibility of interacting with the model and, in this way, they stays more motivated [4]. Practice and training in virtual worlds are important factors to achieve the required level of competencies and collaboration between academy and industry can generate proper scenarios for real practices. Applications like virtual training envir-

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onments, virtual prototyping of designs, and joint virtual development of information systems require a valid representation of the real environment. The aim is to achieve a complete analysis of reality through including the perspectives of experts in several areas of knowledge. It is the way to attain a fully defined reality. The processes and results achieved in situ tasks and the subsequent analysis will create the ideal resources for incorporation into educational tasks. Often, the real environments are building facilities such as construction, management and maintenance. This is the case of the applications presented in this text. Thus, it is possible to train new researchers and professionals in the engineering activity using RV applications.

4D modeling (3D+time) and VR techniques are currently in use both in the construction activity and in education. Concerning the educational task, the interaction allowed by three-dimensional geometric models (3D) could make an end to passive attitudes of learners as an opposition to traditional teaching systems. In addition, VR technology could be applied as a complement to 3D modeling, leading to a better communication between the various stakeholders in the process, whether in training, in education or in professional practice. This task is particularly relevant to the presentation of processes which are defined through sequential stages as generally is the case in the learning of new curricular subjects, as well the construction processes. A previous work was defined, concerning didactic applications that illustrate clearly this point of view.

At the Department of Civil Engineering of the Technical University of Lisbon, some didactic models have already been generated (Fig. 1): 3D geometric models that support the activity concerning the rehabilitation of buildings [5]; and VR models developed to support classes in Civil Engineering (wall, bridge and roof construction) namely Technical Drawing, Construction and Bridge disciplines [6]. At present, these didactic VR models are in common use in both face-to-face classes and within e-learning platforms. The professors who teach the construction and bridges courses use the models when they introduce the topics represented in those models. Thus, the models follow with great efficiency and detail the construction sequence, the explanation of the themes related to the construction of bridges and rehabilitation.

These virtual environments are especially valuable because they allow training in a virtual way representing real—world situations, like the construction place. Training in the real place is impractical because it is logistically difficult, dangerous, and too difficult to control. Compelling virtual environments could lead human participants to feel somehow present, for purposes of training. Part of the components involved in the interactive virtual training environment are simulated, the operator nevertheless can experience a similar sense of being present and interacting with real/ virtual objects via visual. Virtual environments can assist with the use of equipment operation training and novices have much more time to practice their skills without the pressure of costs. The mentioned didactic VR models allow the interaction with the equipment in the virtual work place. So practice and training in virtual worlds representing real worlds are important factors to achieve the required level of competencies and collaboration between academy and industry can generate proper scenarios for real practices [7]. Time and experience permit problem categorizing, so the contact of engineering students with new technologies in the early stages of their learning and training process is important. The teacher is the responsible educator of creating an educational environment, such as it is the case for the creation of a self-study or practice [8].

The research work presented in this paper follows on from that previous educational work. The more recent models were created within a research project developed at the Department of Civil Engineering, concerning the implementation of virtual models as tools to support decision-making in the planning of construction management and maintenance [9].This paper describes three prototype applications based on VR technology for use in the construction of buildings activity:

- The first, applied to construction [10], is an interactive virtual model designed to present plans three-dimensionally (3D), connecting

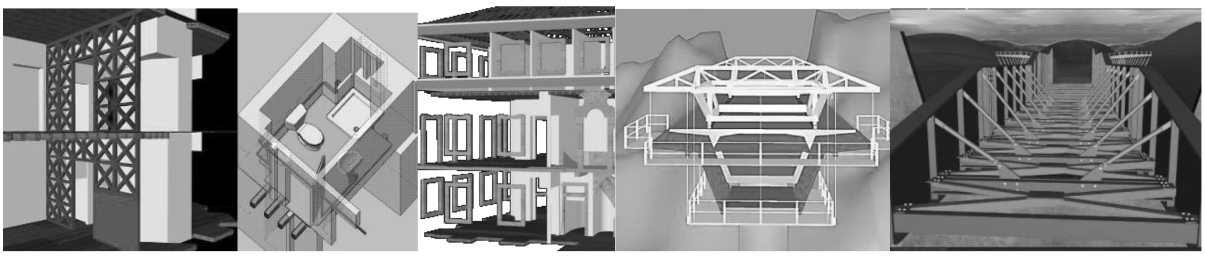


Fig. 1. 3D models concerning the rehabilitation activity and VR models showing bridge constructions.

them to construction planning schedules, resulting in a valuable asset to the monitoring of the development of construction activity. The 4D application considers the time factor showing the 3D geometry of the different steps of the construction activity, according to the plan established for the construction. The models allow interaction with the 3D geometric model of a building, visualizing each construction step and the corresponding photo obtained at the construction site;

- The two other applications concern the maintenance activity. In a building, the paint coating applied to interior walls [11] and the different type of materials applied to façades [12] 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 completed models support the performance of such periodic inspections and the monitoring of interior and exterior wall maintenance, using VR technology. Used during an inspection visit, the applications allow users to consult a database of irregularities, normally associated with the coating, classified by the most probable causes and by recommended repair methodologies. In addition, with the interior walls 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. This 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 scholarships holders involved, in this work, are 5th year students of Civil Engineering. Teach CAD and VR in school is helpful to students in order to prepare them to consider this technology as an important support, later in professional activity, and also to facilitate the link between, engineering theory and its implementation. These applications are part of M.S. thesis developed in the area of Construction at the Technical University of Lisbon. They had to learn advanced software of geometric modeling and visualization and to explore the capacities of a RV technology system. In addition, a bibliographic research support had to be made regarding the planning and maintenance of constructions. Also programming skills had to be adapted to establish the integration needed for the creation of the models. Furthermore, the structure of different kind of databases had to be studied and implemented, integrating diverse type of information, needed to develop the interactive virtual model. In addition, a method of action will be established with a view to the generalization of the process of generating virtual models from 3D models. It will be promulgated in education, in related disciplines and training courses and on a professional level, to those offices concerned with lifecycle facilities management. In the definition of these interactive applications the students had to study several concepts and learn how to use different software in order to implement useful models in specific areas. The VR models were defined with friendly interfaces oriented to the principal users, the engineers, and they contain the most important information required when the engineer carries out the monitoring of a construction or a maintenance inspection in a building.

Advantages of 4D virtual environments are found in improving communication, increasing insight, supporting collaboration, and supporting decision-making [13]. The divergence in 3D virtual applications requires different type of requisites of the real environment [14]. This can be illustrated by the different VR models developed, and presented in this text, to motorize the construction or maintenance activity or for educational propose, both in the Civil Engineering domain. The authors have been developing several applications in different branches of knowledge which have been successfully implemented in construction and maintenance [15] [16]. This text intends essentially to highlight the new possibilities that the use of VR could bring to engineering education to support research works and after on the activity of the students as professionals.

2. 4D/VR Model of construction planning

There is an increase in use of 3D virtual environments in architecture, engineering, and construction (AEC) industries [17–18]. Frequently, the design drawings are complex, show different layers, steps or details, and therefore become hard to understand. The 3D visualization can be used as a platform for shared understanding to be used by every participant involved in the design process. For the presentation of the final result to stakeholders, a 3D visualization with a reduced level of complexity is preferred. For the geometric description are employed graphics techniques like CAD. The different types of visualizations, both in 2D and 3D, achieve different types of fidelity for each specific goal.

Construction project planning has been considered as a critical process in the early project phases that determines the successful implementation and delivery of project [19]. During this stage, project planners need to develop main construction strategies, to establish construction path and assembly sequences, and to arrange construction methods and resources required for the execution of work packages. Such shortcomings of traditional communication tools together with the advances in digital technologies have stimulated various research and development efforts to develop new innovative construction process planning techniques in order to enhance the visualization of the construction sequence and finished product. The latest research development relates to the development of graphical presentation of construction plan via the four-dimensional (4D) geometric models (i.e. 4D-Planner). A 4D CAD model is generated from the combination of 3D graphic images and the time. The 4D visualization technique provides an effective means for communicating temporal and spatial information to project participants. Finished projects are visualized and spatial configurations directly shown. Visualization of construction plans allows the project team to be more creative in providing and testing solutions by means of viewing the simulated time-lapse representation of corresponding construction sequences [20].

A prototype based on VR technology with application to these demands of construction planning, was created [10]. This interactive virtual model presents the project in 3D, integrated with the construction planning schedule, resulting in a valuable asset in monitoring the development of the construction activity, compared to the construction planning already drawn up. The 4D application allows the time factor to be considered in conjunction with the 3D geometry of the different steps of the construction activity, according to the schedule established for the construction, thus offering a detailed analysis of the construction project. Additionally, VR technology allows the visualization of different stages of the construction and interaction with the real-time construction activity. This application clearly shows the constructive process, avoiding inaccuracies and building errors, thereby facilitating better communication between partners in the construction process. This application was developed in three stages:

- Planning takes into consideration the final purpose of the presentation, and the definition of tasks; the details, therefore have to be in line with this idea. Using *Microsoft Project*, the tasks are introduced and the relations between them defined;
- Geometric modeling needs to relate correctly to the tasks as defined at the planning stage. Using *AutoCAD* as a modeling tool, the layers make the distinction between the different tasks and elements are created in enough detail to support correct comprehension. The application also presents a real-time illustration of the evolution of the construction through photographs of the site, taken at specific points in time;
- The third stage, integration of the first two stages, makes use of two programs. *EON Studio 5.0* (2010) and *Microsoft Visual C# Express Edition*, where the first takes the 3D model created with AutoCAD and introduces it in the application developed using the second.

Construction management can be defined as the planning, co-ordination and control of a project from conception to completion (including commissioning) on behalf of a client [21]. This requires the identification of the client's objectives in terms of usage, function, quality, time and cost, and the establishment of relationships between the people involved, integrating, monitoring and controlling the contributors to the project and their output, and evaluating and selecting alternative solutions in pursuit of the client's satisfaction with the outcome of the project. It is essential, therefore, that the project designer has the depth of knowledge to be able to correctly identify the different stages of the construction planning, as well as to take into consideration the logistics and resources involved in the project [22]. The construction planning used in the implemented prototype is realistic and considers the graphic and written documentation, measurements and quantities map, specifications and regulations relevant to the project.

As a method of testing the application, a construction project was undertaken, more particularly, the structure of a building, using both its graphic documentation, that is, the architectural and structural blueprints, and the project description and construction planning (Fig. 2). The whole project was simplified to serve the academic purposes: the list of tasks was defined based on the more characteristic stages of a construction process, and a few tasks focused on the construction details of certain elements. As a result, *AutoCAD* layers were created for each task defined and the 3D model constructed. When finished, the 3D model was exported to *EON Studio* [23], where a diagram of events was created, after which the application was ready to be used. All steps have been modeled and linked to the planning chart.

The application, developed in C#, integrates all the components described with the interface as shown in Fig. 3. The application is organized as follows: Virtual model; pictures of construction site; planning task list; Gantt map. The interface is organized so that it can be used easily by the designer or engineer at work.

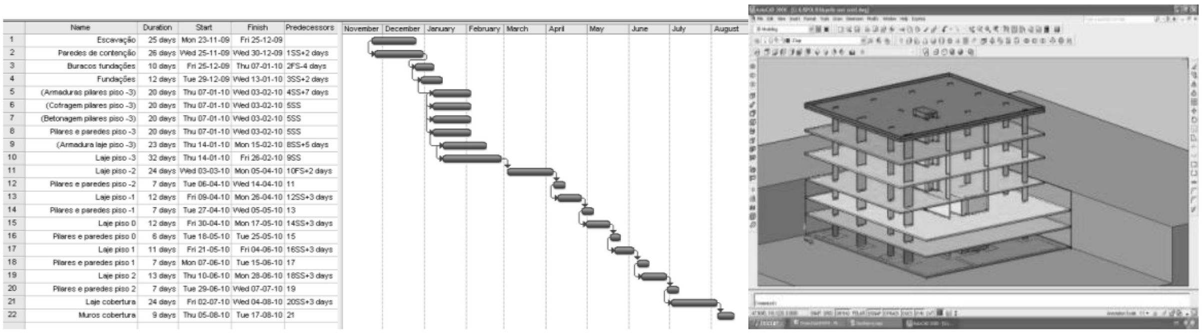


Fig. 2. Construction planning (list and Gantt map) and the 3D model of the building structure.

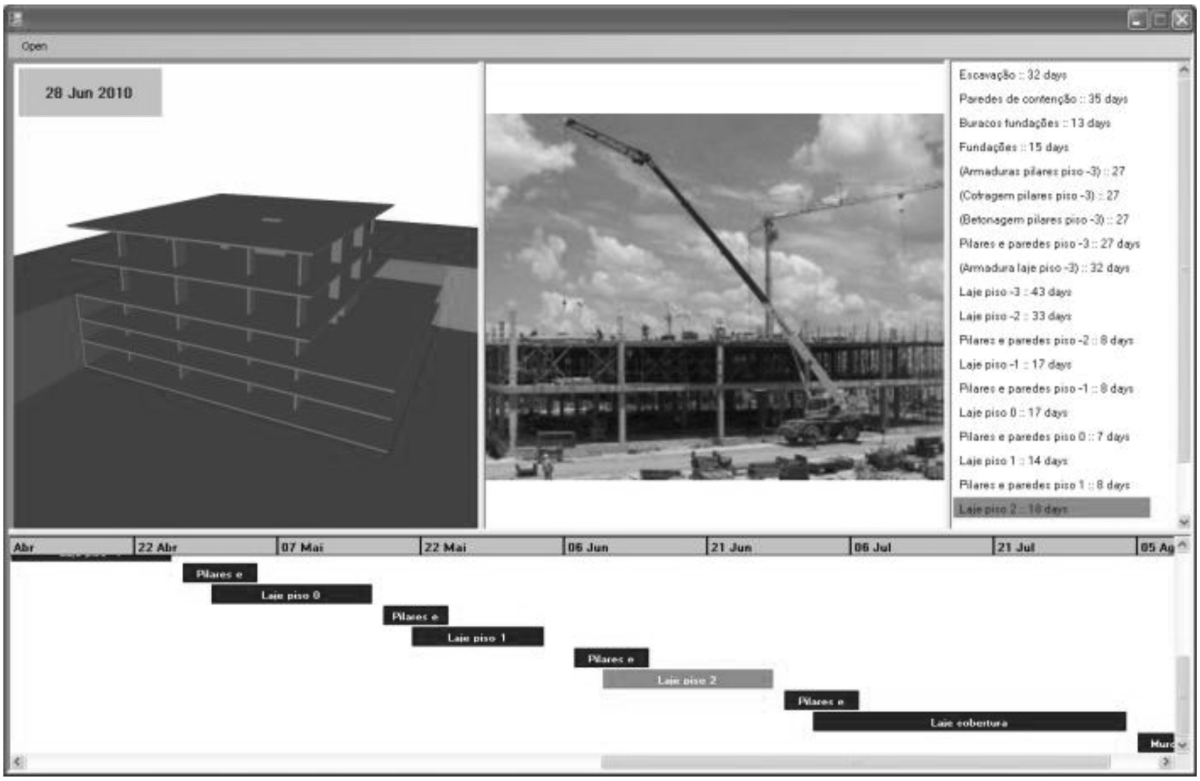


Fig. 3. Application interface.

2.1 Interaction with the application

The interaction with the application is made through Planning task list and Gantt map. Both the task list items and Gantt map bars are buttons which, when pressed, send the information to the *EON* for the task selected, and in return *EON* presents the model in the current state, that is, it shows and hides specific elements depending on the specific stage of the construction. So, in the application, the geometric model of the building is presented in a sequence simulating the construction activity (Fig. 4). For that, each modeled component of the building is connected to the programming instruction: *hidden* and *unhidden*. The task list and the virtual model are connected: when selecting a task, the relevant construction stage is presented. The first scenario is the landscape and then the foundation work is shown. The date for each visualized task is shown in the upper left corner of the virtual model window. *EON Studio* also offers the possibility of changing the material associated with each element, creating a more realistic model.

Some construction details have also been modeled and included in the task list. Progress across three different stages, of one of the columns and a detail of the reinforcement and concrete of a slab, are shown in Fig. 5. In addition the control of the position and orientation of a camera (position, zoom and orientation of the model in relation to the observer) must be defined in accordance with the selected construction step. So, a first position of the camera is defined in order to allow the user to visualize adequately the selected detail of the building. After that the user is free to walkthrough inside and around the model. For that the user must interact with the 3D model through the VR window of the interface. The user can manipulate the virtual model, in order to choose the identical perspective as that shown in the photo. So, with the visualization of what is planned and what has been done in the real building, the construction work can be better compared and analyzed (Fig. 5).

2.2 Industrial application aspects

In construction industry, from the conception to the actual implementation, project designs are presented mostly on paper, even though the two dimensional reading is often not enough, as mistakes can be introduced in early stages of conception or elements misunderstood on the construction site. 3D models present an alternative to avoid inaccuracies, as all the information can be included with the necessary detail. Computer systems used in construction for graphic representation have experienced a vast evolution, allowing new ways of creating and presenting projects. 4D models, also labeled as 3D evolutionary models, permit a better comprehension of the project throughout its life, minimizing the information loss through the chain of events. In construction management, over the years, technical drawings have played a crucial role in communication between the numerous partners in a project. In addition VR technology was here presented a step-by-step guide in assembling complex structures in an interactive way. One of the benefits of this VR application in construction is the possibility of a virtual scenario being visited by the different specialists, exchanging ideas and correcting mistakes. So, this application already offers the possibility of communication between different specialties while developing a mutual project. In this field 4D models promote the interaction between the geometric model and construction activity planning, allowing immediate perception of the evolution of the work. In planning, in correct evaluation and the meeting of needs as they arise, 4D models constitute a positive contribution to decision-making when establishing planning strategies [24].

The developed construction model brings an innovative aspect to 4D modeling as usually applied to construction planning, through the incorporation of pictures into the interface of the VR model, an important support element in the comparison between what is planned and what is in progress in situ after each construction task. When constructing a building, the planning sometimes needs to be changed due to unexpected occurrences. Implementing these changes in the prototype is actually very simple, as the user has only attribute new start and finishes dates to the task in *MS Project* and load the new file into the application. Any new objects can be introduced into the application, just by modeling the new elements considering their positions relative to the ones already in the simulation and programming the associated action in *EON*. Likewise, the application accepts any kind of construction project, as long as its implementation imperatives are met. Additionally, with the appropriate models, it can also be used in construction site management.

The interface of the interactive application was established to provide easier interaction with the 3D model, and to focus the attention of the user on the important sections of each task, guiding them through the proper course of development of the construction. The principal innovative contribution of the model is the incorporation of updated pictures taken in situ. It helps designer to follow adequately the construction process and he can introduce the necessary changes in the construction plan previously established. The weakness of this prototype lies in the time needed to carry out the preparation for the actual interaction with the application. Modeling a building may not be very extensive. The programming of the actions in *EON Studio*, however, can be time-consuming.

2.3 Didactics features

With the development of the virtual application the student had to:

- Develop their capabilities of 3D modeling, creating 3D models based on the reading and interpretation of graphic documentation of project structures, which is presented in the form of 2D drawing;
- Stud the issues related to the construction planning and how to establish appropriate planning case study, learn how to use the construction planning software, *Microsoft Project*, and how to define a plan for the building structural part of a building in the form of a list of activities and in the form of a Gantt map;
- Learn how to use software concerning an innovative technology, the *EON* technology-based Virtual Reality, in the definition of an application with capabilities of interaction;
- Finally, how to implement a virtual model by linking the different software's based on the establishment of friendly interfaces in *Visual C#* programming language, and so their basic knowledge of programming learned during the degree.

So, after the development of this project, the skills of the student are added making it suitable for the development of work in his future professional

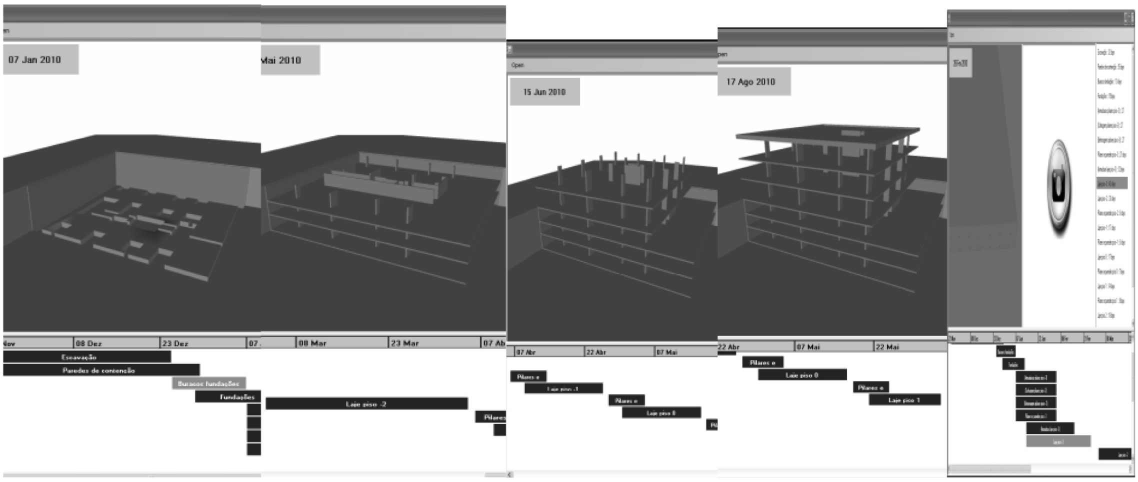


Fig. 4. Sequence of the construction process.

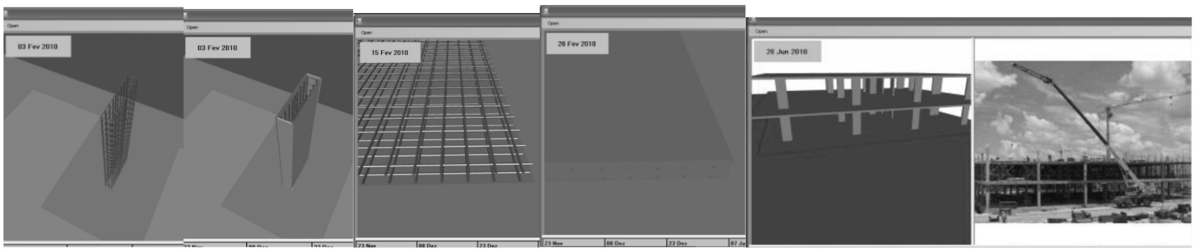


Fig. 5. Column and slab construction: reinforcement, formwork and concreting and rotation applied to the model.

activity in engineering, drawing on knowledge of innovative technology applied to the construction area.

This application acts also as a didactic model. It is used in classrooms and web platforms. In face-to-face classes the teacher uses the model as a support to the introduction of subjects concerning the construction of a building structure and the link to the construction plane. Using the 4D/RV model, each constructive step is presented in a sequential and animated manner, controlled interactively by the teacher. The model can support properly the explanation for each construction step. The model has advantages in the activity of teaching by allowing the visualization of the physical evolution of the construction process and the most adequate zoom in order to observe the geometric details of each component. The teacher interacts with the models at a speed that is most convenient for the description of each issue.

3. 4D/VR Model of inspection and maintenance

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 constitutes an important support in the management of buildings allowing interaction and data visualization. At present, the management of building planning can be presented in 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 [25]. This study contemplates the incorporation of the 4th dimension, that is, time, into the concept of visualization and concerning the changing of data. The focus of the work is on travelling through time, or the ability to view a product or its components at different points in time throughout their life. In maintenance, the time variable in the 4D model is related to the progressive deterioration of the materials throughout the building's lifecycle. It is implicit 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.

This item describes the implementation of two interactive models concerning façades and painted interior walls, highlighting the constitution of the database supporting each model, and the organization of a user-friendly interface designed to be used by an inspection worker. During the construction of these models, 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. The main aspects of the maintenance of buildings with a focus on maintenance of painted walls and façades were study. Then the anomalies that most often originate in the wall finish, which are listed in an identical manner to that used in the virtual model database. In addition, methods of interconnecting this knowledge with the virtual model are explored. These aspects of the construction activity are in constant evolution, so require the study of preventive maintenance, though, for example, the planning of periodic local inspections and corrective maintenance with repair activity analysis [26]. For this reason, the models facilitate the visual and interactive access to results, supporting the drawing-up of inspection reports. These 4D virtual prototypes were trailed in an actual project. Each 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 and façades in terms of maintenance, throughout the life-cycle of the building.

3.1 Maintenance

The General Regulations for Urban Buildings (RGEU) [27] 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, defects sometimes registered during the construction of property developments, exacerbating the poor state of repair of the buildings. 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 [28]. 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. According to Cóias [29], the purpose of maintenance is to prolong the useful life of the building. Satisfactory management of this activity must be carried out by putting into practice a maintenance plan which must take into consideration technical, economic, and functional aspects arising with each case. Collen [30] points out that some measures have already begun to be implemented like the creating of some urban regeneration programs focuses on the sustainability of buildings with the objective of guaranteeing that the maintenance of built heritage be an integral part of the construction sector.

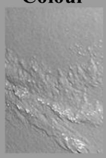
The maintenance of buildings, then, is an activity of considerable importance within the construction industry; its contributory aspects of conservation and rehabilitation work need to be supported by correct methodologies of action, underpinned by scientific criteria and by suitable processes for the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

3.2 Interior walls painted model

The technical document Paints, Varnishes and Painted Coatings for Civil Construction [31] defines paint as a mixture essentially made up of pigments, binder, vehicle and additives. 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 [32]. 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 [33]. 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. The information gained from the pathological analysis of this type of coating was used to draw up a database supporting the interactive application. 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 1, were considered. This classification provides the required auto-

Table 1. Classification of Irregularities and Causes

Classification	*Irregularity*	*Repair methodology*	*Characteristics and causes*
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	- A yellow colour caused by ageing of the film of the paint or varnish;
	Bronzing		- Action of environmental agents (solar radiation, temperature oxygen and humidity) on the binder in the paint provoking changes in its molecular structure.
	Fading		- Partial loss of colour of the film of paint coating;
	Discolouration		- 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.

matism of access to the database and supports the presentation of synopses of the causes and repair methodology inherent in each pathology.

The developed VR application supports on-site inspections and the on-going analysis of the evolution of the degree of deterioration of the painted coating of interior walls of buildings [11]. The main interface of the application, shown in Fig.6, gives access to the virtual model of the building and to the inspection and maintenance modules. The first step when using the application is to make a detailed description of the building (location, year of construction, type of structure, etc. Fig. 6). A wall surface in each of the rooms of the house is a component which has to be monitored and, therefore, to be identified. Associated to each selected element is the information regarding location within the house (hall, kitchen, bedroom), wall type (simple internal masonry wall) and coating (paint), as shown also in Fig. 6. 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.

Later, on an on-site inspection visit, the element to be analyzed it selected interactively on the virtual model. The inspection sheet (Fig. 7) is accessed by using the *Inspection* button which is found in the main interface. The data which identify the selected element are transferred to the initial data boxes on the displayed page (*hall*, *simple internal masonry wall* and *paint*). 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 (Fig. 7). The current size of the pathology should also be indicated since it reveals how serious it is (*area of pathology*, Fig. 7). In the field *Observations* (Fig. 7), the inspector can add any relevant comment, 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 analyses (field *Number of pathologies*, Fig. 7) and other elements can be analyses and recorded and anomalies observed. Later, the files thus created, associated to each of the virtual model elements, can be consulted (*Case history* button in the Interface in Fig. 7). This same window allows all the data referring to the building and to the completed inspection to be shown, in *pdf* format (Fig. 7). Later, after having been carried out repair work it is possible to upgrade the virtual model, adding the results of a new inspection, the corresponding comments relating to the intervention of the work and the photos taken after the execution of works. So,

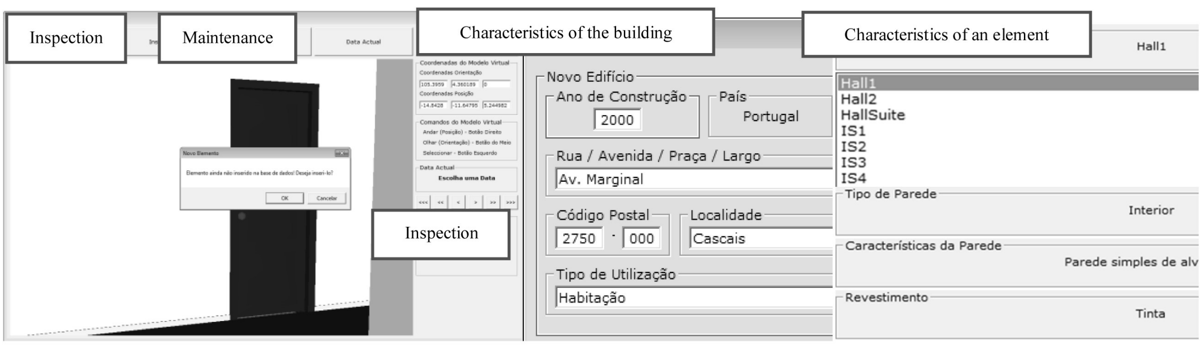


Fig. 6. The main interface of the virtual application and identification of the building and an element.

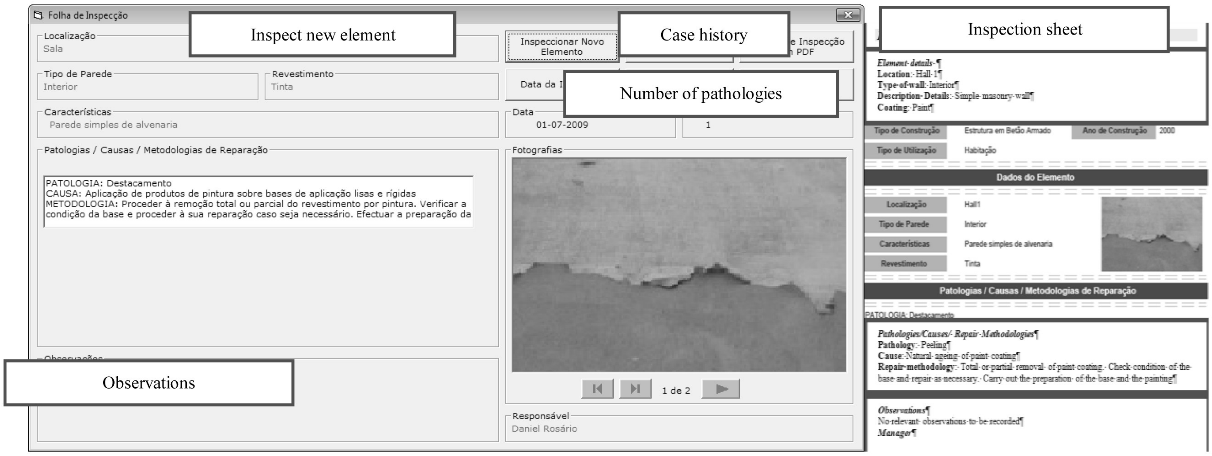


Fig. 7. Interface of the inspection sheet and the *pdf* inspection report.

the virtual model can keep updated a history of inspections of repairs in the building.

In addition the implemented VR model allows the user to monitor the evolution of wear and tear on the paint coating in a building by observation of the change of color applied on painted walls. 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 (Fig. 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 repair*, Fig. 8).

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. 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 (Fig. 8).

3.3 *Façades model*

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 a physical, chemical or biological nature. Naturally, they should also give the façade the required decorative effect. Since this building component is exposed to adverse atmospheric conditions it frequently shows an evident degree of deterioration, requiring maintenance work. In order to arrive at the best solution for eventual maintenance and repair work, a survey of defects and deterioration must be conducted.

In order to better understand the operation of façade coating, bibliographic research of materials usually applied to this type of material 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

Fig. 8. Chromatic alteration of the coating according to its state of deterioration.

Fig. 9. Different types of materials applied as façade coatings and some irregularities.

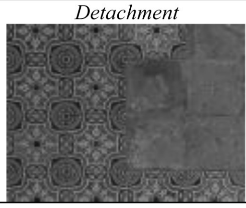
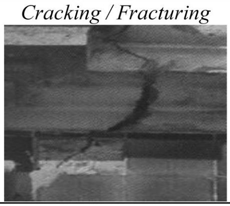
of time on the performance of these exterior closure materials require an understanding of their characteristics [34] (Fig. 9): types of material (painted surfaces, natural stone panels and ceramic wall tiles); application processes (stones, ceramic tiles, painted surfaces; anomalies (dust and dirt, lasting lotus leaf effect, etc.); repair work (surface cleaning, wire truss reinforcing, cleaning and pointing of stonework joints, etc.).

The most frequent anomalies that occur in the coated façades were analyzed in order to create a database linked to the virtual model that could support the planning of inspections and maintenance strategies in buildings. This 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 type of anomaly the most adequate repair solutions were also selected and included in the database. The example of Table 2, concerning deficiencies in tiles, illustrates the methodology implemented in this virtual application.

The virtual application uses an interactive 4D visualization system based on the selection of elements directly within the virtual world. 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 (Fig. 10). 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, various inspection reports can be defined and recorded and thereafter consulted when needed. An inspection sheet is accessed from the main interface (Fig. 10). All coatings studied were considered in this the data base. The element interface sheet exposes the data element identifiers (type of covering, area, etc.) and then allows the selection from among the listed anomalies associated with the type of covering material of the element, which is the anomaly observed on site (Fig. 11). In addition it is possible to select the possible cause, the appropriate repair methodology related to the anomaly observed, and the photos taken at the site. In this way, each element can then support characterization data of the applied material and different kinds of information related to inspection.

Table 2. Example of anomalies and the associated repair solution

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

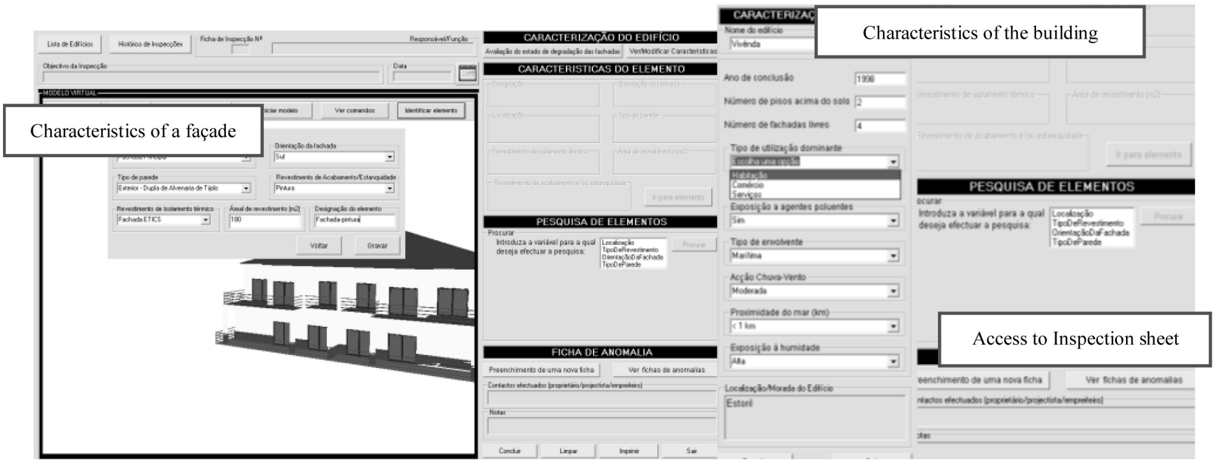


Fig. 10. The main interface of the interactive application.

After the completion of the series of inspections required for building façade elements the user can interact with the virtual building model. Each element is identified by user by clicking over the virtual model element and then the corresponding information is displayed. In addition, the presentation of the inspection report can be shown in the form of a *pdf* file (Fig. 12).

The developed software is easy to handle and transport for on-site inspections and comprises information of the causes, solutions and methods for repairing anomalies supporting an inspection visit.

3.4 Industrial application aspects

The inspection process requires one or more visits to the site of the building [35]. Normally, the inspection process of buildings is based on filling out paper files during the site survey. So, 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

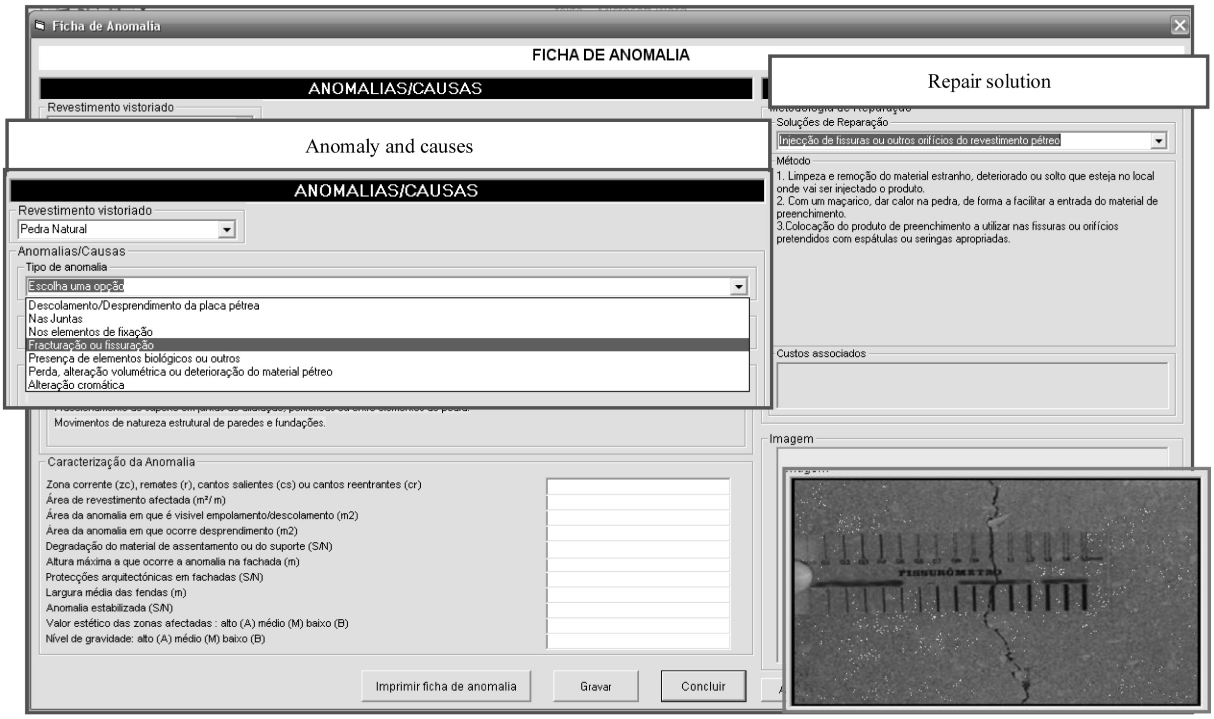


Fig. 11. The inspection interface of an element.

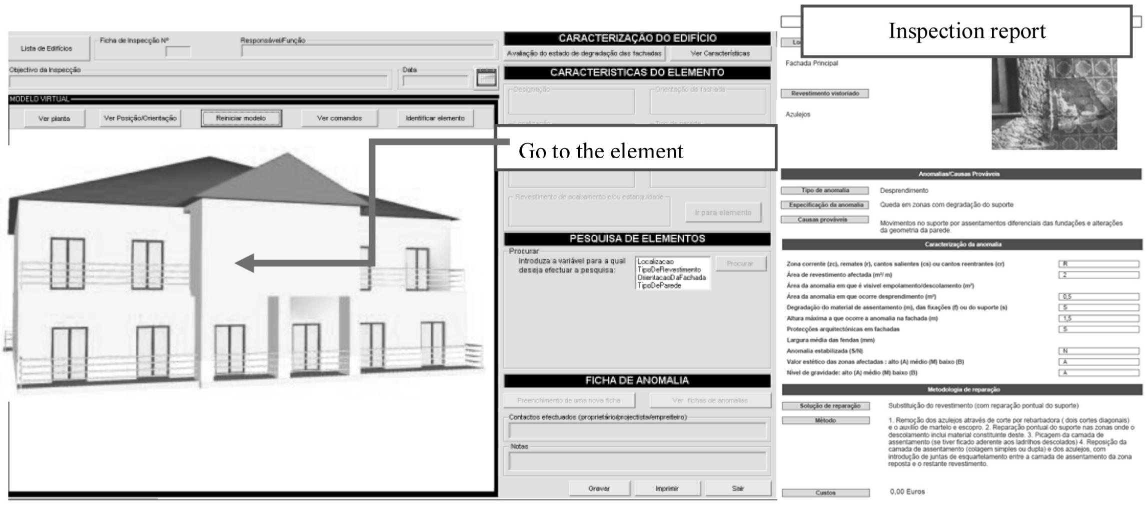


Fig. 12. Identification of a façade element and an inspection sheet report.

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.

The VR models support the maintenance of interior and exterior walls enabling the visual and interactive transmission of information related to the physical behavior of the elements. Both models show the characteristics of each element of the building in the model and the information related to inspection, anomalies and repair works. 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. 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.

As each 3D model is linked to a database in an interactive environment and has a user-friendly interface with easily manipulation of the data, it engenders a collaborative system [36]. With these applications, the user may fully interact with the programs referring to each virtual model at any stage of the maintenance process and can analyze the best solution for repair work. These applications can also support the planning of maintenance strategies and promote 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. Many potential users are not computer experts; so, human perceptual and cognitive capabilities were taken into account when designing the visualization applications, namely the interfaces, with the result that the model is easy to use and does not require sophisticated computer skills.

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.

3.5 Didactic characteristics

Besides the constant updating of training in the new graphic resources available to engineering and architecture professions, and in widespread and frequent use, the school should also adapt its teaching activities to the new tools of visual communication. In fact, several software engineering is used today in the construction industry, which requires that future civil engineers have the competencies and knowledge to develop economical and feasible solutions [37]. Undergraduate students must be educated and trained to perform the roles required for software development in order to create effective solutions. It is necessary that the educator find and use resources supporting different issues in civil engineering field. Resources should be introduced into the training of the student, leading to their adaptation for curricula in drawing and geometric modeling disciplines. And they feel much more motivated if they learn how to use innovative technologies such as VR and integrated in a research project with direct application on the construction activity.

The models relating to the maintenance of buildings constitute part of the research project and also they are part of Bologna thesis. So they are part of the curriculum of the Master in Civil Engineering. Teaching and research are complementary in these works. Students gain skills to use VR-based software that can be used later in his activity. The developed computer applications have a positive contribution to make in the field of the construction industry, using IT tools which give access to innovative technology with it capacity for interaction and visualization. The models integrate VR technology and applications implemented in *Visual Basic* (VB) language. The following computational systems were used in development of both VR applications: *AutoCAD*, in the creation of the 3D model of the building; *EON studio* for the programming of the interactivity capacities integrated with the geometric model; *Microsoft Office Access*, to establish suitable databases; *Visual Basic* in the creation of all the windows of the applications and in the establishment of links between components. All systems are available in the computer lab (ISTAR [38]) of the Department for use by students and researchers at the Technical University of Lisbon.

The applications act also as didactic models concerning maintenance. The models are actually used in face-to-face classes of the discipline of Construction Process (4th year) of Civil Engineering curriculum. The teacher interacts with the model showing the problems of maintenance concerning buildings. When the student, of the 4th year, goes to a real inspection visit he can use the VR application and select in the list of anomalies the most adequate irregularity and the correspondent repair work. So, they better understand the maintenance issue previously explained in class. The students reflected on their evaluation works a better understanding of subjects concerning maintenance. For instance, when the students went to a work place, they position more there attention to some kind of details presented in the VR models. Teachers realized that the students' reports of visits to work places include some aspects shown in the virtual models and they are more detailed. So, these models are beneficial to students. When the VR models are placed on the web pages of their respective disciplines, the student has free access to the model and can observe the constructive process ahead or kicking steps and visualize, with the most appropriate point of view and zoom, the geometric detail of some elements or interconnection mode between the various components of the building. The models presented in the classroom, or through a web platform can provide additional knowledge. Both situations are currently used in teaching Construction discipline of the Civil Engineering Department.

4. Conclusions

Virtual Reality technology with its capability of interaction and connectivity between elements was employed in the developed prototypes within a research project, offering several benefits both in presenting and developing projects, in supporting decision-making in the maintenance domain and also in teaching activity.

Technical drawings and explanatory texts often have little detail and are frequently insufficient in fully comprehending a construction activity. Using VR models means that mistakes can more easily be caught before construction starts, which translates into time and cost reduction. The construction planning model can be used with any kind of construction project and, being a flexible application, accepts new data when necessary, allowing for a comparison between the planned and the constructed. The prototype can also be expanded to include other aspects of construction management, such as resource administration, or to have real-time access to the construction, through the use of cameras installed on site. The use of new mobile technologies could move the application to the construction site, clarifying any doubts about location or position of each component.

The maintenance models support the global analysis of the need for repair tasks in a building, helping the designer to define an adequate plan of rehabilitation work. Using the virtual application to support an inspection visit 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. For that the databases were 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 each virtual model in an inspection situation. The specialist must choose in each case the most appropriate sequence. The definition of the repair plan is based on the analysis of the data entered and selected in the system. An additional innovation concerns the incorporation of the capacity of changing the color of the painted wall with the time parameter. So the evolution of the deterioration of the coating material is visualized through the alteration in color, when walking-through the virtual model. The plan must incorporate the repair of all anomalies detected during an inspection visit, which are reported, with the help of the VR models, it, too, bringing economic benefits.

An engineering school can be expected to constantly update computational resources which are in frequent use in the professions. Civil Engineering students were educated and trained to perform the roles required for software development in order to create effective solutions. Time and experience permit better resolution of problems, so the contact of engineering students with new technologies in the final stage of their learning and training process is important. It is necessary that the educator can find and use resources supporting different issues in Civil Engineering field. The author as a teacher has been supervising educational and professional studies, such as it is the case for the creation of a self-study or practice. CAD and VR techniques were applied on the production of educational materials and on research works within Bologna thesis. The interaction with the VR didactic models helps student to better understand the diversity of the engineer activity. Practice and training in virtual worlds are important factors to achieve the required level of competencies and collaboration between academy and industry can generate proper scenarios for real practices. Applications like virtual training environments and virtual prototyping of planning construction and management were created. The aim of the research works was essentially to provide students skills and expertizes in several areas of knowledge using an emergent information technology.

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