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Didactic Models in Civil Engineering Education: Virtual Simulation of Construction Works

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1. Introduction

Concerning educational tasks, the interaction allowed by three-dimensional (3D) geometric models could bring an end to passive learner attitudes which are often found in traditional academic teaching situations. In addition, Virtual Reality (VR) technology could be applied as a complement to 3D modelling, leading to better communication between the various stakeholders in the process, whether in training, in education or in professional practice. This role 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. Besides this constant updating of training in the new graphic resources available to and in widespread and frequent use in professions in the fields of engineering or architecture, the school should also adapt its teaching activities to the new tools of visual communication. In fact, today, in practical subjects a variety of engineering software is used, but this requires skills and knowledge to develop economical and feasible solutions.

Educational institutions can use communication technology to access information, as a form of collaboration and communication with teachers, or as a tool for conveying educational contents, as well as a means of online teaching. A communication platform allows participants to exchange information about specific domains and interact and learn cooperatively, therefore, an aspect that must be improved is the preparation of didactic materials to support teaching (Gomes & Caldeira, 2004).

Today, 3D models and VR technology are used in engineering schools to aid both the lecturers and students. They offer students the opportunity to visualize the engineering concepts they learn in the classroom. Gibbon, in Electrical Engineering, uses laboratories containing operational amplifiers and a resonant circuit, based in 3D modelling tools in order to achieve a better understanding of circuit issues presented in formal lectures (Gibbon, 2008). Other examples of computer simulation and VR projects supporting the teaching of engineering students are remote physics experiments (Ozvoldova et al., 2006), simulation control testing (Su et al., 2006) and virtual laboratories (Safigianni & Pournaras, 2008).

Techniques of 3D modelling and VR were applied to the development of models related to the construction process. The 3D models created to support rehabilitation design emerge as an important tool for the monitoring of anomalies in structures and to assist decisions based on the visual analyses of alternative solutions. Didactic interactive models showing

construction works were also developed. These applications allow the visual simulation of the physical progression of each type of work and also assist in the study of the necessary equipment needed and how it functions on site. The introduction of CAD and VR techniques in school is helpful to students in order to prepare them to consider these technologies as important supports, later in their professional practice.

The aim of the practical application of the didactic virtual models is to provide support in Civil Engineering education namely in those disciplines relating to drawing, bridges and construction process both in classroom-based education and in distance learning based on e-learning technology. Engineering construction work models were created, from which it was possible to obtain 3D models corresponding to different states of their shape, simulating distinct stages of the carrying out processes. In order to create models, which could visually simulate the progressive sequence of the process and allowing interact with it, techniques of virtual reality were used. Virtual instruments could complete or replace the experimental part in various cases. These applications allow users to conduct process and present briefly fundamental theory of the phenomena or provide full information concerning the experiments. So, the educational virtual experiments must be well framed in the lesson context.

In addition VR technology was applied on the development of a model concerning the management of lighting systems in buildings. It allows the visual and interactive transmission of information related to the physical behaviour of the elements, defined as a function of the time variable. The model was created by students involved in a research project. This kind of work gives the student capacities to develop, after in there professional activity, software that can help them to resolve engineering problems using the VR technology. That's a new tool that they know how to use.

2. VR models in AEC

The use of CAD and VR systems is helpful in areas such as Architecture, Engineering and Construction (AEC). However, the introduction of these new technologies into designers' actual practice has been anything but smooth (Duarte, 2007). At present, when carrying out a project, the use of graphic systems and, in particular, those relating to 3D modelling, makes a very positive contribution towards improving the transmission of rigorously correct technical information and, in general, to the understanding of spatial configurations in their environment. This means of expression surpasses a drawing, a picture or a diagram (Sampaio & Henriques, 2008).

Virtual Reality is a technology that allows users to explore and manipulate, in real time, computer-generated 3D interactive environment. This technology offers advantages such as: representational fidelity with a high degree of realism caused by the rendering capacity for objects; the ability to look at objects from different viewpoints, and the ability to pick up, examine and modify components within the virtual world; the feeling of presence or immersion, as a consequence of the realism of the images and a high degree of interaction. It makes the VR environment motivating and engaging by giving the users the possibility to be part of the world, and by allowing them to focus entirely on the task in hand.

VR is also seen today as an integrating technology, with great potential for communication between project participants, and most recently, as a tool for the support of decision-making, made possible by the integration of specific computer applications in the virtual model.

2.1 Construction

The results of the architectural design of a building are usually several drawings, which, lately, are often complemented by 3D models. Architects create 3D models of houses so that their clients can more clearly understand what the house will look like when built.

Models concerning construction need to be able to generate changes in the project geometry. The integration of geometric representations of a building together with scheduling data related to construction planning information is the basis of 4D (3D + time) models. Thus, in this field, 4D models combine 3D models with the project timeline, and VR technology has been used to render 4D models more realistic allowing interaction with the environment representing the construction site. 4D models are being used to improve the production, analysis, design management and construction information in many phases and areas of construction projects (Fischer & Kunz, 2004). VTT Building Technology has been developing and implementing applications based on this technique providing better communication between the partners in a construction project (Leinonen et al., 2003). Note the contribution of VR to support conception design (Petzold et al., 2007), to introduce the plan (Khanzode et al., 2007) and to follow the progress of constructions (Fischer, 2000).

The didactic VR models presented in the text shows the sequence of construction processes allowing step-by-step visualization. The models concern a wall, as a significant component of a building, two methods of bridge construction, each with different degrees of detail and technical information and a roof, namely the graphical process. The target users of these models are Civil Engineering students. Here, the VR technology was applied for educational purposes.

2.2 Maintenance of buildings

The main aim of a research project, which is 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. The virtual models give the capacity to transmit, visually and interactively, information related to the physical behaviour of materials, components of given infrastructures, defined as a function of the time variable. In this context, the research project presents the development of a VR application, involving knowledge of the physical aspects of materials, particularly those which have a short-term function. This knowledge includes their use and environmental factors, and the application integrates these items into digital spatial representations. In this way, the indisputable advantage of the ease of interpretation and perception of space provided by the visualization of 3D models, and of the technical content underlying the real characteristics of the observed elements are brought together. The interactive application allows decisions to be made on conception options in the definition of plans for maintenance and management.

In farther work, several elements have been studied and implemented in the same virtual application. Until now, the model includes exterior closure of walls and façades, and, now in progress is the implementation of the floor element. The characteristics of different surfaces materials have been implemented as have some strategies of maintenance and rehabilitation for these construction elements of a building. The goal is to generate a model that can analyse, from a management perspective, the most important components of the building, a model which must be interactive.

A first prototype concerning the lighting system was developed (Sampaio et al., 2009). It integrates VR system and a computer application implemented in Visual Basic (VB)

language. The model allows the examination of the physical model, visualizing, for each element modelled in 3D and linked to a database, the corresponding technical information concerned with the wear and tear aspects of the material, defined for that period of time. In addition, the analysis of solutions for maintenance work or substitution and inherent cost are predicted, the results being obtained interactively and visibly in the virtual environment itself. In addition the model of lighting management can support analyses of preventive maintenance, the application in larger building and the study of the effects of lighting intensity.

3. Didactic models

The aim of the practical application of the virtual models is to provide support in Civil Engineering education namely in those disciplines relating to drawing, bridges and construction process both in classroom-based education and in distance learning based on e-learning technology. Engineering construction work models were created, from which it was possible to obtain 3D models corresponding to different states of their shape, simulating distinct stages of the carrying out processes. In order to create models, which could visually simulate the progressive sequence of the process and allowing interact with it, techniques of virtual reality were used. Virtual instruments could complete or replace the experimental part in various cases. These applications allow users to conduct process and present briefly fundamental theory of the phenomena or provide full information concerning the experiments. So, the educational virtual experiments must be well framed in the lesson context.

Specialist in construction processes and bridge design were consulted and implicated in the execution of the educational models in order to obtain efficient and accurate didactic applications:

a. In construction, the selected examples are three elementary situations of works, one concerns the execution of an external wall, a basic component of a building (Sampaio & Henriques, 2007), the second presents the cantilever method of bridge deck construction (Sampaio et al., 2006), a frequent construction technique and the last attends the incremental launching method of bridge deck construction (Martins & Sampaio, 2009). The developed applications make it possible to show the physical evolution of the works, the monitoring of the planned construction sequence, and the visualization of details of the form of every component of each construction. They also assist the study of the type and method of operation of the equipment necessary for these construction methodologies;

b. The roof model supports the explanation of subject matter pertaining to elevation projection representations applied to the design of roofs (Sampaio et al. 2009). This model presents the method of designing a roof using the usual graphic elements of plan drawing but displaying them in their 3D form. The model shows in animation the intersection between two simple roofs in order to explain how to define a more complex roof. In this way the model supports the learning of the methodology pertaining to the practical aspects in drawing roofs.

The pedagogic aspect and the technical knowledge are presented on the selection of the quantity and type of elements to show in each virtual model, on the sequence of exhibition to follow, on the relationship established between the components of both type of construction, on the degree of geometric details needed to present and on the technical

information that must go with each constructive step. Further details complement, in a positive way, the educational applications bringing to them more utility and efficiency. Namely, the model of the wall shows the information concerning construction activity of interest for students corresponding to the geometric stage displayed in each moment and the cantilever deck construction model shows particularly the movement of the equipment in operation during the progressive activity. So when students go to visit real work places, since the essential details were previously presented and explained in class, they are able to better understand the construction operation they are seeing.

When modelling 3D environments a clear intention of what to show must be planned, because the objects to display and the details of each one must be appropriated to the goal the teacher or designer want to achieve with the model. For instance, if the objective is to explain the relationship between construction phases and the financial stages, the 4D model must represent the correspondent physical situation according to the established construction diagram and with the degree of detail appropriated. Developing didactic models for students concerns technical tasks, at a level that could be understood by undergraduate students, but also demands pedagogical attitudes.

In addition, the use of techniques of virtual reality on the development of these didactic applications is helpful to education improving the efficiency of the models in the way it allows the interactivity with the simulated environment of each activity. The virtual model can be manipulated interactively allowing the teacher or student to monitor the physical evolution of the work and the construction activities inherent in its progression. This type of model allows the participant to interact in an intuitive manner with the 3D space, to repeat the sequence or task until the desired level of proficiency or skill has been achieved and to perform in a safe environment. Therefore, this new concept of VR technology applied to didactic models brings new perspectives to the teaching of subjects in Civil Engineering education.

3.1 Model of the wall

The model of a masonry cavity wall corresponds to one of the basic components of a standard construction. To enable the visual simulation of the wall construction, the geometric model generated is composed of a set of elements, each representing one component of the construction. The definition of the 3D model of an exterior wall of a conventional building comprises (Fig. 1): the structural elements (foundations, columns and beams), the vertical filler panels (with the thermal isolation plate placed between the brick panels and the stone slabs placed on the exterior surface) and two cavity elements (door and window).
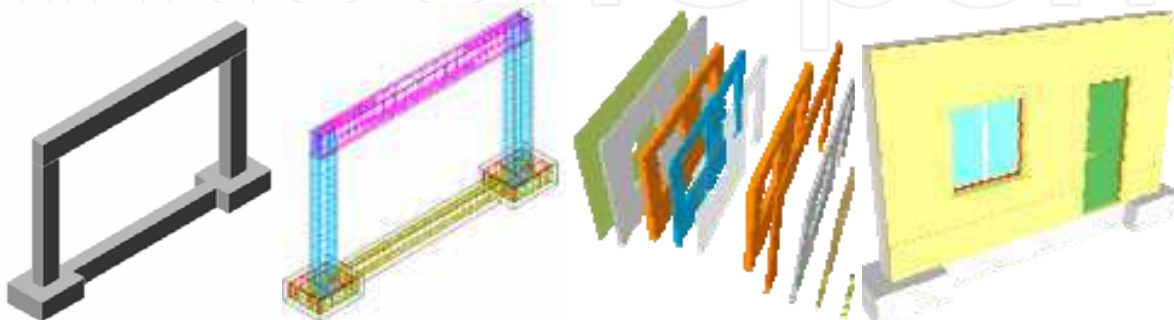

Fig. 1. Steel reinforcements 3D models of the structural elements, the vertical filler panels and the door and window openings.

The complete geometric model was transferred to the VR system *EON* (EON, 2009). In this system, the visual simulation of the wall building process was programmed, following a realistic plan of the construction progress. The order in which components are consecutively exhibited and incorporated into the virtual model, properly represent the real evolution of the wall under construction (Fig. 2): (a) During the animation, the student can control the length of time that any phase is exhibited and observe the model using the most suitable camera and zoom positions for a correct perception of the details of construction elements;
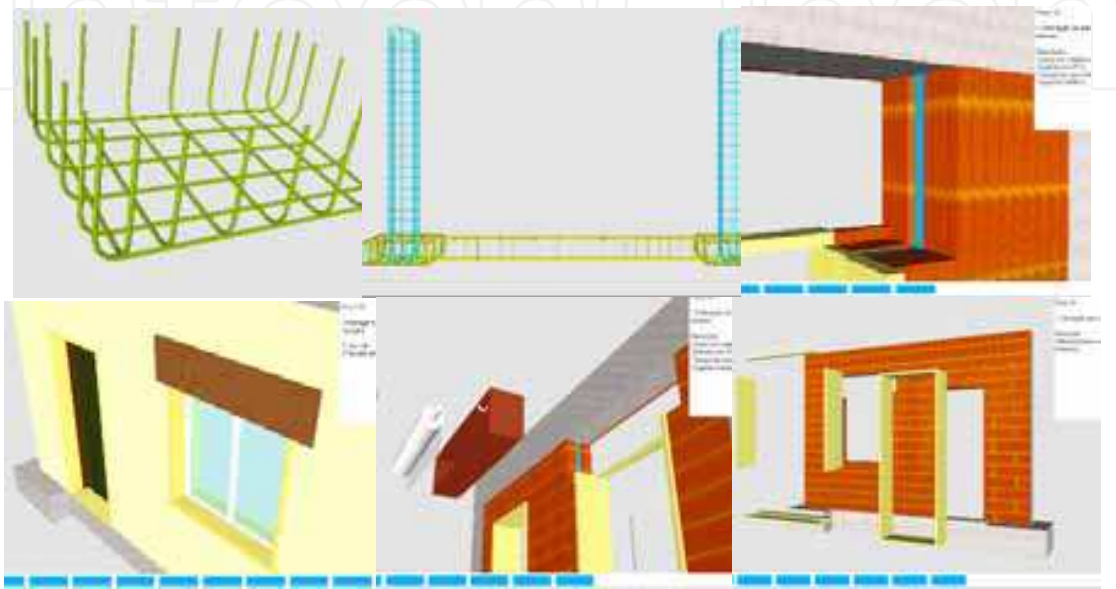
Fig. 2. Time length control, zoom positions and elements from the global model of the wall.

(b) It is possible to highlight the incorporated component at each new phase and to examine it in detail; (c) Included, under the window in which the virtual scene is exhibited, is a bar, which shows the progress of the construction. Throughout the animation, the bar is progressively filled, with small rectangles symbolizing the percentage of each phase, in relation to the completed wall construction. Through symbols it represents the diagrams normally used on construction plans; (d) Simultaneously, with the visualization of each phase, a text is shown (in the upper right corner of the window), giving data related to the shown stage, namely, its position within the construction sequence, the description of the activity and the material characteristics of the element incorporated.

The development of the model was supported by a specialised engineer working in construction which guarantees that the model shows a valid construction sequence and that the configuration of each component was defined accurately. The models support CAD and Construction subjects.

3.2 Model of the cantilever method of bridge construction

The second model created allows the visual simulation of the construction of a bridge using the cantilever method. Students are able to interact with the model dictating the rhythm of the process, which allows them to observe details of the advanced equipment and of the elements of the bridge (pillars, deck and abutments). The sequence is defined according to the norms of planning in this type of work.

The North Viaduct of the Bridge Farm, in Madeira, Portugal, was the case selected for representation in the virtual environment. In cross-section, the deck of the viaduct shows a box girder solution, its height varying in a parabolic way along its three spans. The most common construction technique for this typology is the cantilever method. A computer graphic system which enables the geometric modelling of a bridge deck of box girder typology was used to generate, 3D models of deck segments necessary for the visual simulation of the construction of the bridge (Fig. 3).
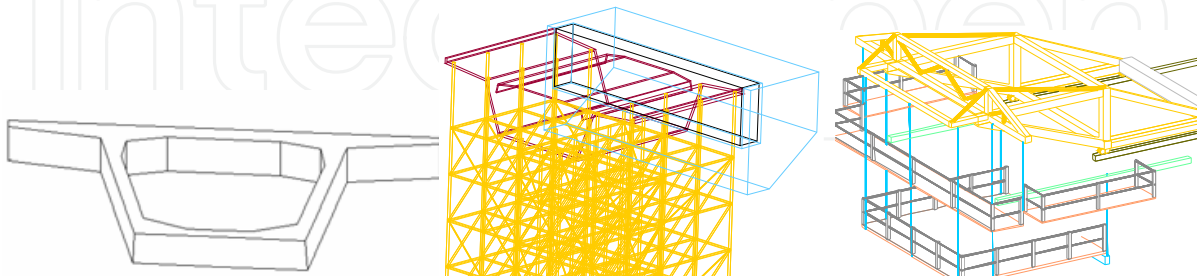
Fig. 3. 3D model of a deck segment, the scaffolding and the advanced equipment.

To complete the model of the bridge, the pillars and abutments were modelled. Then followed the modelling of the advanced equipment, which is composed not only of the form traveller, but also the formwork adaptable to the size of each segment, the work platforms for each formwork and the rails along which the carriages run (Fig. 3). As, along with the abutments, the deck is concreted with the false work on the ground, the scaffolding for placement at each end of the deck was also modelled (Fig. 3). The 3D model of the construction environment was then transposed to the virtual reality *EON system*.

The support of a bridge design specialist was essential in obtaining an accurate model, not only of the geometry definition of components of the bridge and devices, but also of the establishment of the progression sequence and of the way the equipment operates (Fig. 4): (a) This method starts by applying concrete to a first segment on each pillar, the segment being long enough to install the work equipment on it; (b) The construction of the deck proceeds with the symmetrical execution of the segments starting from each pillar, using the advanced equipment; (c) The continuation of the deck, joining the cantilever spans, is completed with the positioning of the closing segment; (d) Finally, the zone of the deck near the supports is constructed, using a false work resting on the ground.
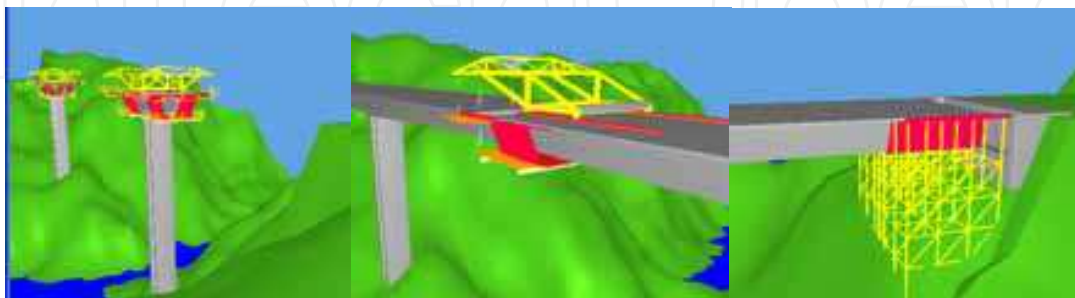

Fig. 4. Sequence of the bridge deck construction.

Moving the camera closer to the bridge model and applying to it routes around the zone of interest, the student, interacting with the virtual model, can follow the sequence specifications and observe the details of the configurations of the elements involved (Fig. 5).
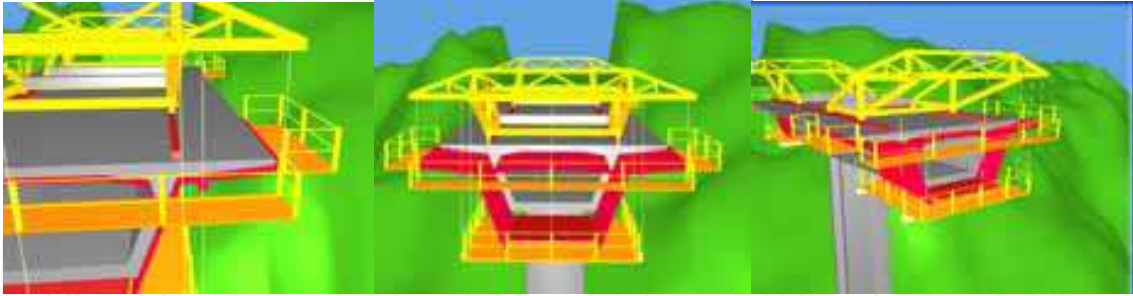
Fig. 5. Camera positioned closer to the model.

3.3 Model of the incremental launching method of bridge construction

Another interactive model concerning construction of deck bridges to support Civil Engineering education was created. The construction of bridge decks using the method on incremental launching has existed since the 60s. The incremental launching method consists of casting 15m to 30m long segments of the bridge deck in a stationary formwork which push a completed segment forward with hydraulic jacks along the bridge axis.

Every element needed in the virtual scenario was modelled and then the interaction was programmed using the some software based on the VR technology, the *EON Studio*. The 3D model of all elements was generated using *AutoCAD*: (a) The metal elements supporting the form and the formwork itself composed by beams and panels, made of wood, were created; (b) To represent the reinforcements a steel mesh was designed; (c) With the objective of allowing some immersive capacity to the model, the river was represented by a surface with mixed colours and the selected panorama simulated a typical environment of river banks.

During the animation, the position of the camera and its movement are synchronized to show the details of the elements or the assembly type and also an overview of the working place (Fig. 6): (a) In order to report an overview of the construction site the camera points initially to the casting yard. At this stage just the abutments, piers and beams of the foundation of the yard are visible. Next, is the building up the exterior form work composed of 26 identical elements, and only the assembly of one element being visualized in detail; (b)
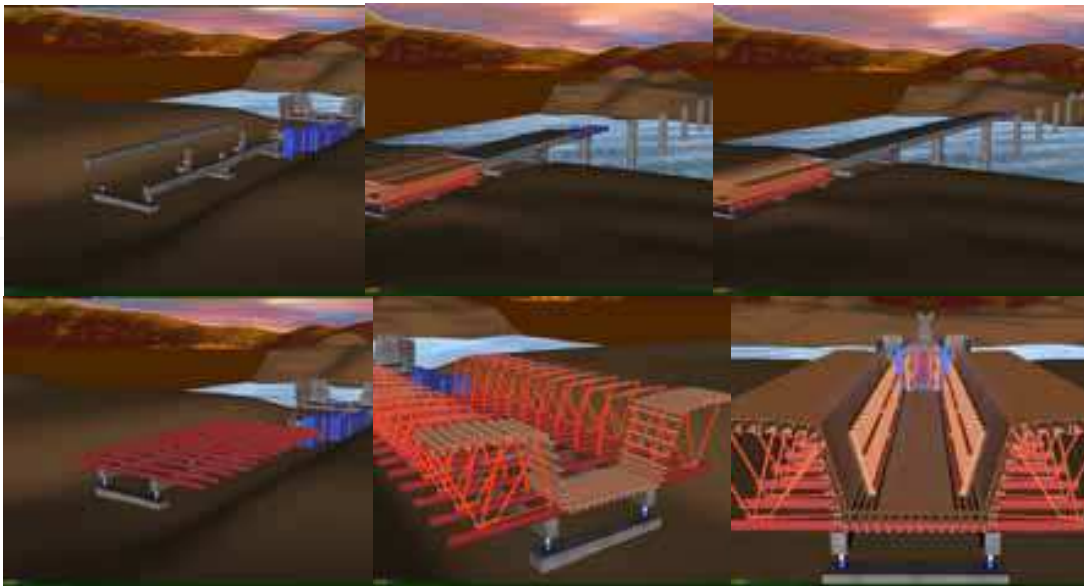

Fig. 6. The casting yard and a sequence of the incremental launches of the deck.

After placing the external panels of the shuttering and the reinforcement mesh, starts the visual simulation of the casting work. The elements that make up the interior false work are placed incrementally, starting with the metallic support, followed by the longitudinal beams and finishing with the implementation of shuttering panels; (c) Next, the assembly of the launching nose is installed. The camera is adjusted to allow the correct visualization of this work. After casting the first segment the displacement of this element takes place. For that the temporary support of the nose is removed and the segment is separated from the shuttering; (d) The arrival of the nose to the first pier is achieved during the advance of the second segment. In it the small brown parallelepipeds are the launch pads and are placed manually by workers between the nose and the temporary support placed over each pier (Fig. 7); (e) Already in the final phase of construction the casting equipment is removed and the area is covered with soil. Finally the guards along with other finishing elements are positioned.

The model was them made accessible to students and teachers of other institutions related to Civil Engineering using the platform developed by the Lisbon Technical University as part of their e-school activities. This model presents a great complexity of geometry and material concerning the different elements used in a real work process. It provides an immersive capacity inherent in the virtual world and it has a menu of events which allows the students and teachers to select a specific part (Fig. 7). The user is able to grasp the most important details of the construction method because of the camera movement which consistently shows the model throughout all the sequences of events: http://www.octaviomartins.com/lancamentoIncremental.
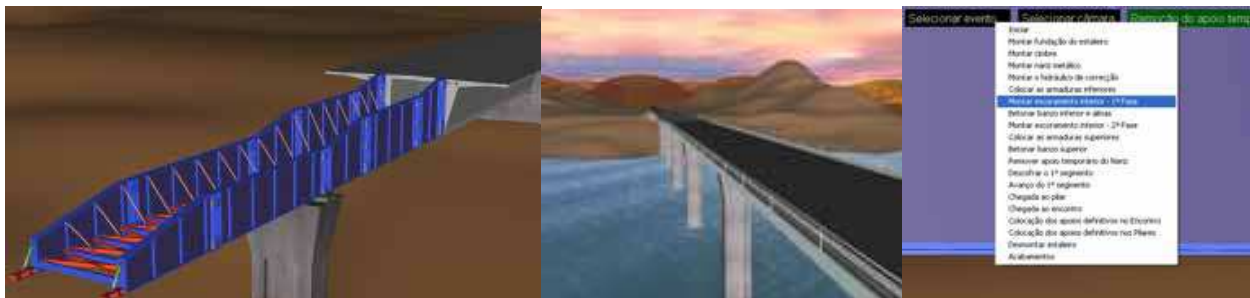

Fig. 7. The metallic launching nose, the guards and a menu of events.

3.4 Model of the roof

Following from those examples, a proposal was put forward to generate an educational model related to the graphic construction of a roof 3D model. Drawings using elevation projection is one of the topics in the subject of Technical Drawing included in the syllabus of the module on Computer Assisted Drawing. This representation uses only the view obtained by horizontal projection, the plan. However, the drawing is complemented by the relevant data, the elevations value and the graphics related to the three-dimensional space.

As far as the roof drawing is concerned the initial data needed are: the specification of the geometric outline of the roof and the slope of each of the roof planes of which it is made up. Based on this information the plan of the corresponding roof is drawn (Fig. 8). So, when defining drawings and 3D models some geometric elements must be used: the slopes represented by their corresponding right-angled triangles and the elevation lines. These are shown traced on a plan but they identify three-dimensional elements (Fig. 8).
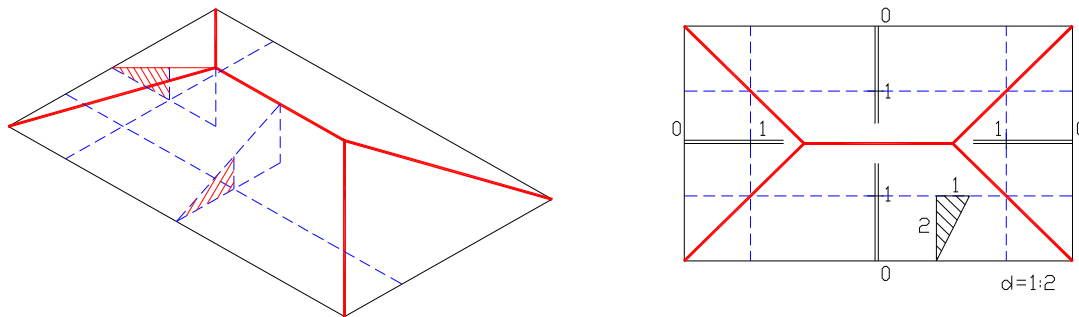
Fig. 8. Perspective and drawing of a roof.

In order to facilitate the ability to understand the spatial aspect inherent in the process, a didactic model was created in which all the methodology underlying its construction is presented in a virtual interactive environment. So, when defining drawings and 3D models of the roof some geometric elements must be used: the base, the slopes represented by their corresponding right-angled triangles and the elevation lines. These are shown traced on a plan but they identify three-dimensional elements. In order to facilitate the ability to understand the spatial aspect inherent in the process, the didactic model presents, in a virtual interactive environment all the methodology underlying the construction of a roof.

Two basic blocks of roof composes the selected example. Fig. 9 shows the outline of the roof under consideration and the slope value for each of the roof planes. When making plan drawings for roofs made up of more than four planes the initial form has to be subdivided into quadrangles. In order to define the virtual environment for the simulation a 3D representation of all its constituent elements was required. The modeling was carried out using *AutoCAD*. The components thus generated were rendered by the virtual reality system *EON Studio*, leading to the definition of the desired interactive animation.
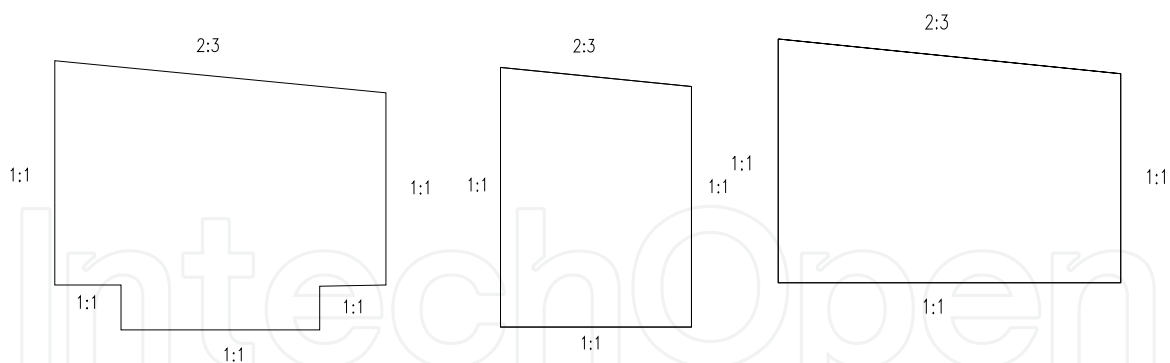

Fig. 9. Initial outline of the roof and gradient of roof planes and the breakdown into two quadrangles.

The model was programmed to show the detailed construction of the roof over one of the trapezoidal bases followed by the process of intersecting the two blocks. Thus solid models had to be used in order to achieve 3D representation (Fig. 10): (a) Two individualized wire-frame trapezoids (the base of two roofs composed of four planes); (b) Two right-angled triangles representing the established value for the slopes of each water-plane (1:1 and 2:3); (c) The unitary elevation roof lines with homogeneous elevation for each of the roof planes, referring to one of the roof block, forming a closed polygonal line; (d) The surfaces of 4 roof water planes for each of the block.
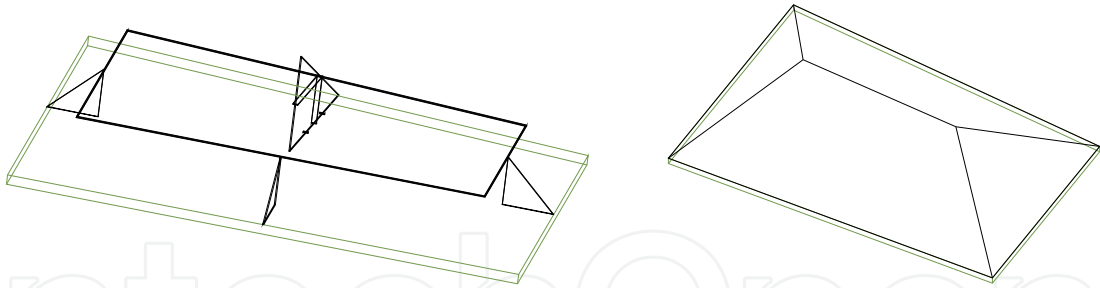
Fig. 10. 3D Models of the graphical elements of the roof.

The animation of the model follows the sequence of operations illustrated in Fig. 11: (a) Presentation of the initial base shape; (b) Subdivision of this shape into two polygons; (c) Placement of the triangle representing the slope value 2:3 next to one of the edges; (d) Insertion of the triangles with 1:1 pitch in normal positions for each of the edges; (e) Introduction of the polygon of the appropriate elevation; (f) Inclusion of the plane surfaces representing the 4 roof planes; (g) Representation of the second of the two blocks which make up the roof; (h) Intersection of the two roof blocks.
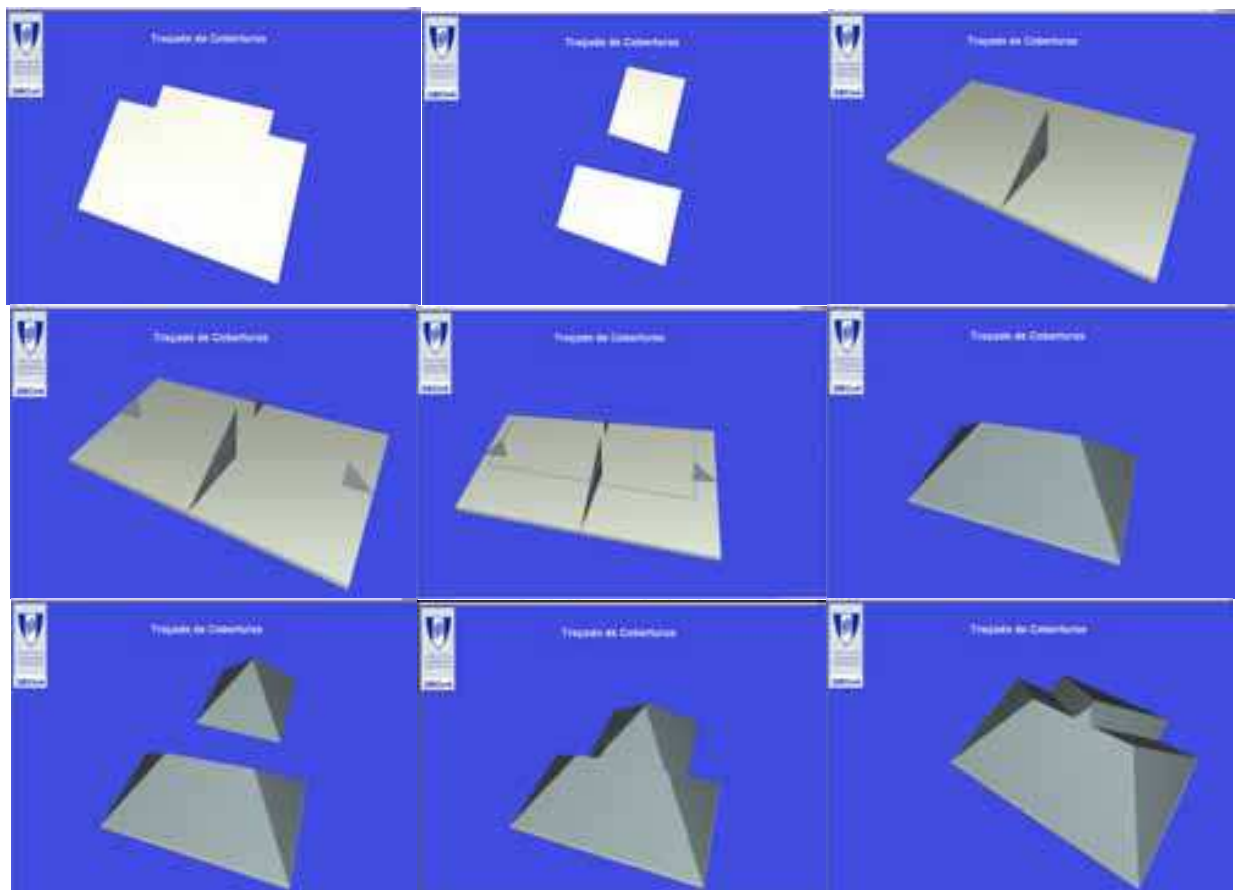
Fig. 11. A sequence of the construction progress.

The model allows interaction with the building process sequence enabling the user to backtrack and manipulate the camera position and distance in relation to the model. The final objective of this model is to show the complete roof constructed on a basis of the concepts of engineering drawing applied to the plan drawing of that structure. The

intersection of the two blocks of the roof clearly illustrates how roofs with more than four planes must be executed (Fig. 12).
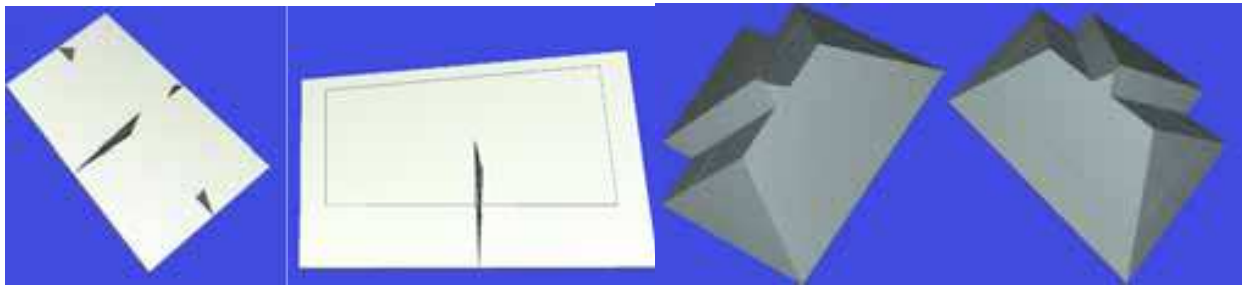

Fig. 12. Backtracking and different viewpoints.

3.5 Learning aspects

At present, didactic models are used in face-to-face classes of subjects of Civil Engineering curricula: Computer Aided Drawing (1st year) Construction Process (4th year) and Bridges (5th year). They are placed on the webpage for each subject thus being available for students to manipulate. The student should download the *EON Viewer* application available at, http://www.eonreality.com/. The traditional way to present the curricular subjects involved in those virtual models are 2D layouts or pictures. Now, the teacher interacts with the 3D models showing the construction sequence and the constitution of the modelled type of work. Essentially, the models are used to introduce new subjects.

As in **Computer Aided Drawing**, students have to define and draw structural plants over the architectural layouts, the virtual model of the wall helps to explain the connection between the architectural drawings and the structural solutions needed to support the building configuration (Fig. 13).
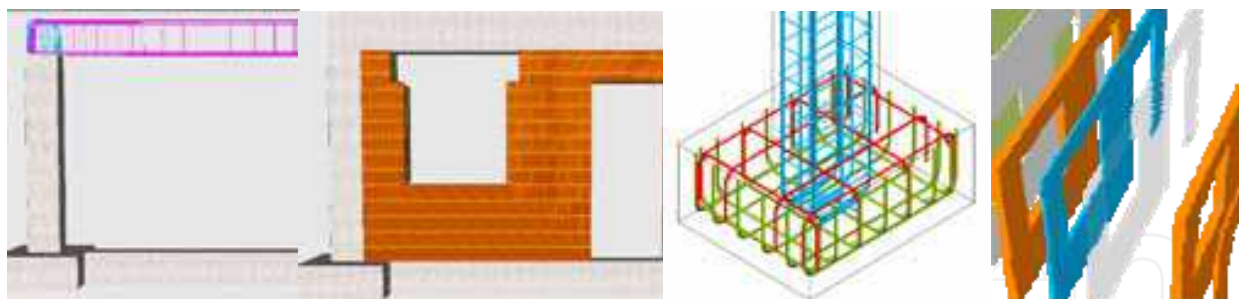

Fig. 13. Details of the virtual model of the wall.

In the discipline of **Construction Process**, in order to prepare students to visit real work sites, the teacher shows the construction animation and explains some items of the construction process of the wall, in particular, the way the iron grid work defined inside a beam or a column and specially the complexity of the relationship between the distinct types of ironwork near the zone where the structural elements connect to each other (Fig. 13). In order to explain this issue related to the structural elements, the iron networks were created as 3D models with distinct colours. They appear on the virtual scenario following a specific planned schedule. In addition, the type, sequence and thickness of each vertical panel that composes a cavity wall are well presented in the virtual model showing, step by step, the relationship between each other (Fig. 13).

The deck **bridge** models, in particular, show the complexity associated to the construction work of the deck and illustrate in detail the movement of the equipment. In class, the teacher must explain why the process must follow both sequence of steps and the way the equipment operates (Fig. 14).

Fig. 14. The models show in detail the movement of the equipment.

When the student, of the 5th year, goes to a real work site he can observe the complexity of the work and better understand the progression of construction previously explained.

The roof model is an educational application to support the discipline **Computer Aided Drawing** (1st year). The issues involved require three-dimensional awareness which, in traditional methods of teaching, transmitted through plane view. This application supports the explanation of topics related to the construction of both simple roofs and more complex ones (that is, those that are more difficult for students to grasp). The model shows, in an animated way, the intersection between two simple blocks defining a more complex roof (Fig. 15).
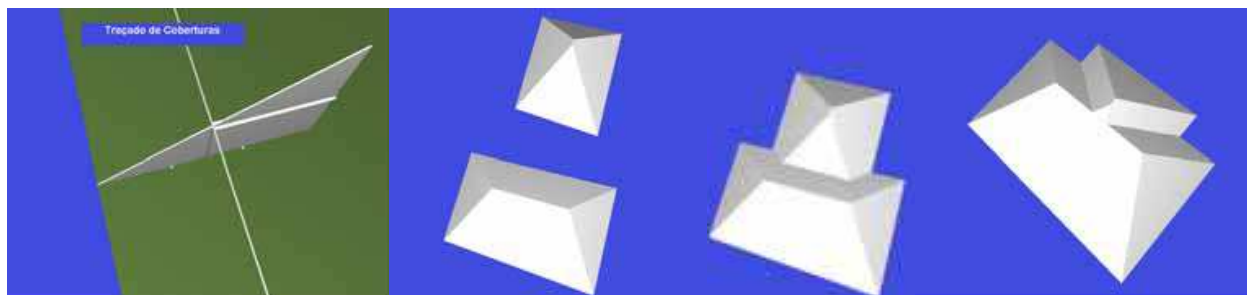

Fig. 15. Definition of a more complex roof based in two simple blocks.

4. The virtual lighting prototype

The first component of the virtual prototype concerns the management of lamps in a lighting system. In addition, the analysis of solutions for substitution and inherent cost are predicted, the results being obtained interactively and shown in the virtual environment itself (Sampaio et al., 2009). Effective integration of advanced visualization capacities is incorporated into the interactive simulation system. The present project integrates a VR system and a computer application implemented in Visual Basic (VB) language. The scholarship holders involved, in this work, are 5th year students of Civil Engineering, who had, therefore, to learn advanced software of geometric modelling and visualization and to explore the capacities of a RV technology system, the *EON Studio*. They had to devise a

research bibliography regarding lamp devices usually applied in a building and they also had to develop their programming skills in order to be able to successfully integrate the elements needed in the creation of a virtual lighting system.

The characteristics of different types of bulbs were collated in order to create a database. An adequate database structure had to be implemented, integrating different types of information, needed to create an efficient and accurate virtual model. The VR model links the 3D objects of the model to this database. The database concerns the lighting system management within a collaborative virtual environment and the respective technical data associated with each component of the model is an integral part of the application, allowing the consultation of required data at any point in time.

4.1 The database

The visualization of information related to lamps requires an understanding of the essential characteristics of those elements and of the planning strategy of lighting system maintenance. The lighting VR model must support the following essential aspects: (a) The system must include a database containing the characteristics of bulb types, with wattage and the corresponding compatibility. These data are important parameters in the drawing up of management schemes. The data base must also include an image of each type of bulb (Fig. 16);
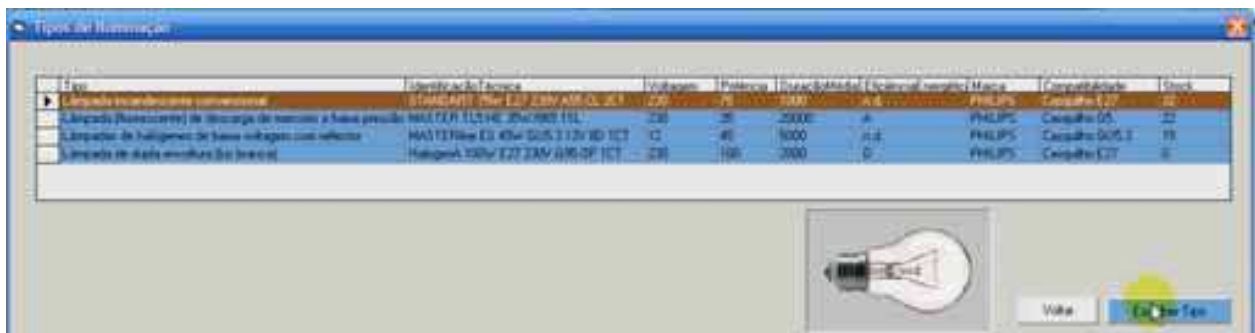

Fig. 16. Details of the database of the model.

(b) A lamp is a replaceable component in a building. As the light source has a discrete lifestyle the VR system must incorporate the control of bulb stock (Fig. 17). The model must include alerts for periodic local inspections of the actual state of each bulb in the building. After inspection, there is an automatic process in which, the compatibility of the socket of each broken bulb can be checked on the database, the element replaced, the installation date and the lighting stock updated;

		Company	*Compatibility*	*Stock*	
ncia	Duraçã				Stock
	1000	n.d.	PHILIPS	Casquilho E27	32
	20000	A	PHILIPS	Casquilho G5	22
	5000	n.d.	PHILIPS	Casquilho GU5.3	15

Fig. 17. Compatibility and stock of bulbs.

(c) The database has other characteristics relating to, light power, energy efficiency and lighting intensity of each bulb type. Based on these parameters the model can calculate the luminosity in a room or analyse the energy efficiency of the whole building (Fig. 18).

Technical identify.	Light power	Energetic	
IdentificaçãoTécnica	Voltagem	Potência	Duração Média	EficiênciaEnergética
STANDART 75W E27 230V A55 CL 2CT	230	75	1000	n.d.
MASTER TL5 HE 35W/865 1SL	230	35	20000	A
MASTERline ES 45W GU5.3 12V 8D 1CT	12	45	5000	n.d.
HalogenA 100W E27 230V G95 OP 1CT	230	100	2000	D

Fig. 18. Some characteristics of bulbs.

The system must calculate as a function of the time parameter the predicted functional life-time of lamps or the time remaining to the next planed inspection. The database therefore, must include for each bulb the installation date, the statistics for its average lifetime, the average number of hours of its predicted functionality and the next periodic inspection date (Fig. 19).

Fig. 19. Interface used to specify data values.

4.2 The 3D geometric model

A 3D geometric model of a building was created. The building consists of a ground-floor, a 1st floor and an attic allocated as living space. The model was generated based on architectural design drawings: plans, vertical views and vertical sections (Fig. 20). Some lighting equipment considered in the building was also modelled and incorporated into the 3D model (Fig. 20). The 3D model was created as 3ds file and exported to *EON Studio*.

4.3 The interface

The process of developing the prototype interface considers the purposes of defining an interactive environment. Human perceptual and cognitive capabilities were taken into account when designing this visualization tool. It uses an interactive 3D visualization
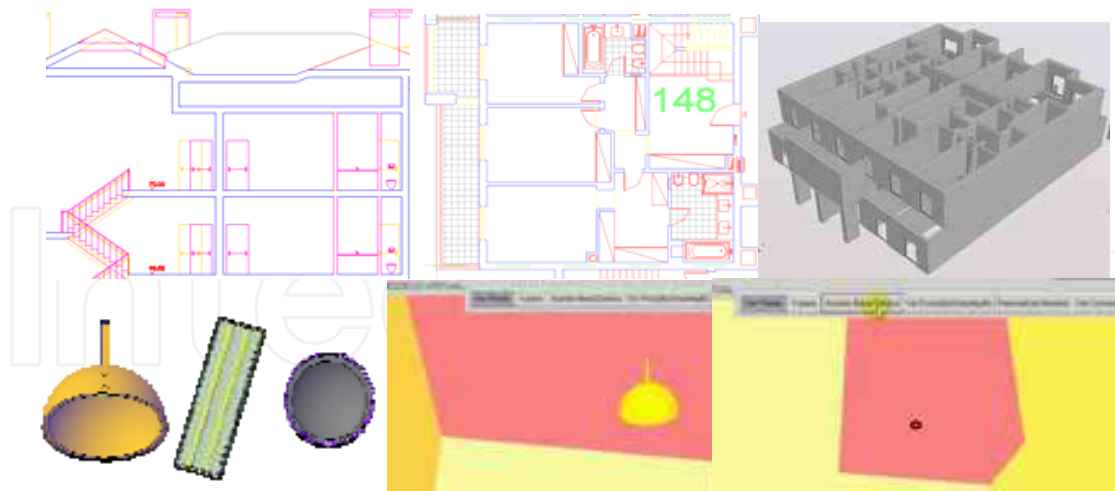
Fig. 20. 3D models of the building and of the lamp devices.

system based on the selection of elements directly within the virtual 3D world. The model enables users to pick up lighting elements, associate values to them and modify characteristics within the virtual world, which makes it easy to use.

First, the lamp is identified as a new element and a bulb is associated to it, together with all information on the chosen bulb included in the database. At this point, the lamp is properly identified as a monitored element. For each element the model allows the determination: (a) Of the predicted break-time for the bulb based on the installation data and the statistic period of lifetime for that type of bulb; (b) Of the temporal data for a specific date of interaction with the model, such as the time remaining to the predicted break-time or the percentage of use (Fig. 21).
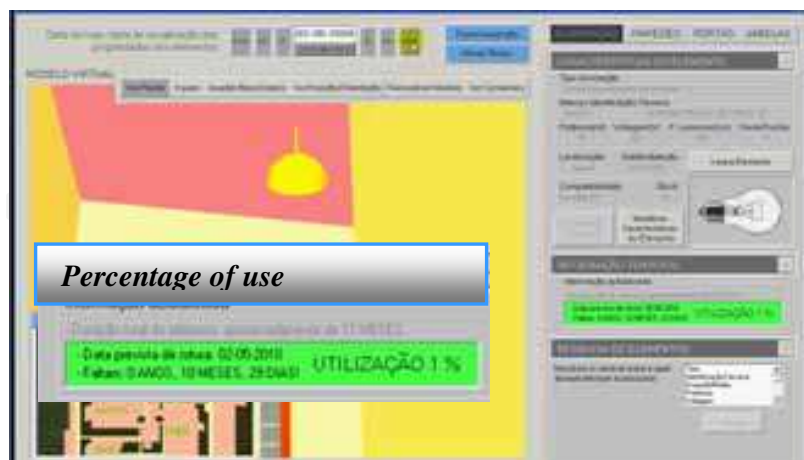

Fig. 21. Temporal data.

The percentage of use changes with the date when the model is used. The colour in the interface that shows this information changes accordingly, from green (less then 20%) to red (near 100%). Fig. 22 illustrates this capacity of the model. When 100% of use is reached an alert message (in red) is shown on the interface.
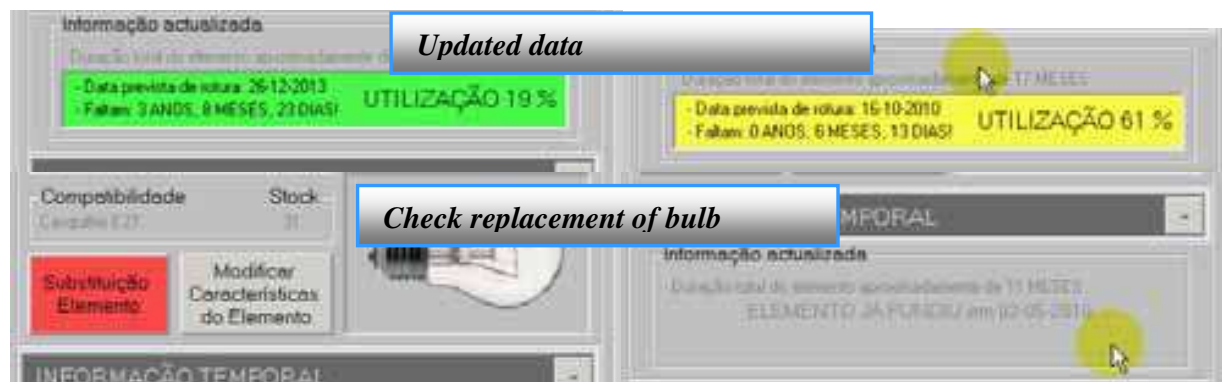
Fig. 22. Colours associated to percentage of use.

4.4 Expected benefits

The virtual model of lighting management can support analyses of preventive maintenance, the application in larger building and the study of the effects of lighting intensity.

Preventive maintenance: All elements of the model must be identified. After that, the model searches by specific characteristics: location within the building (room, kitchen), technical identification (incandescent, halogen), wattage or energetic efficiency. As a strategy of preventive maintenance the light bulbs could be replaced when the time of useful life is nearing its end. In this way, the non-functional period of the lamp left in place can be minimized. The model can list the elements of the building by predicted break-date order. Fig, 23 shows a search by predicted break-date.
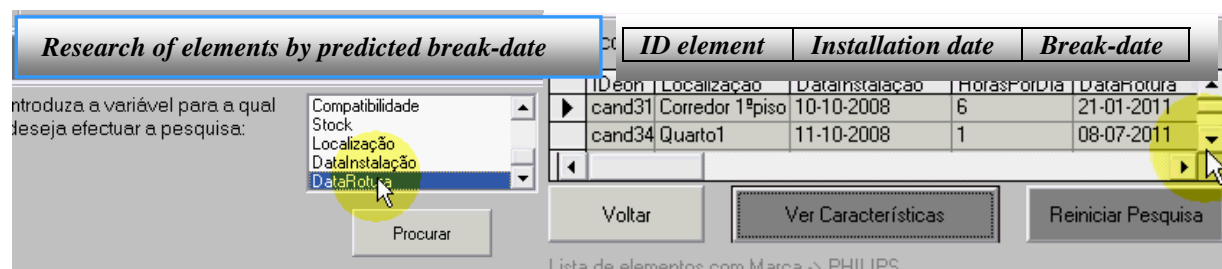

Fig. 23. List of elements ordered by break-date.

Variation of lighting intensity: The VR model allows the control of the lighting intensity of each bulb in a room environment. The *EON* system allows the redefinition of colour obtained by an algorithm of calculation defined as a function of the value of intensity associated with each type of light bulb. A colour is defined as a set of values: R (red), G (green) and B (blue). The algorithm determines a value for each primary colour, defining in this way the colour of the surfaces of the elements in a room. Fig. 24 illustrates different colours controlled by RGB values. This capacity allows the luminosity of a room to be analysed.

Management support on buildings of great dimensions: The application of the VR prototype in buildings of great dimensions, such as hospitals or schools brings benefits since it can support the control of stocks and the management of periodic inspections. Only the 3D geometric model needs to be defined and then this prototype can be automatically incorporated over it, resulting in a virtual model which allows the management of a great
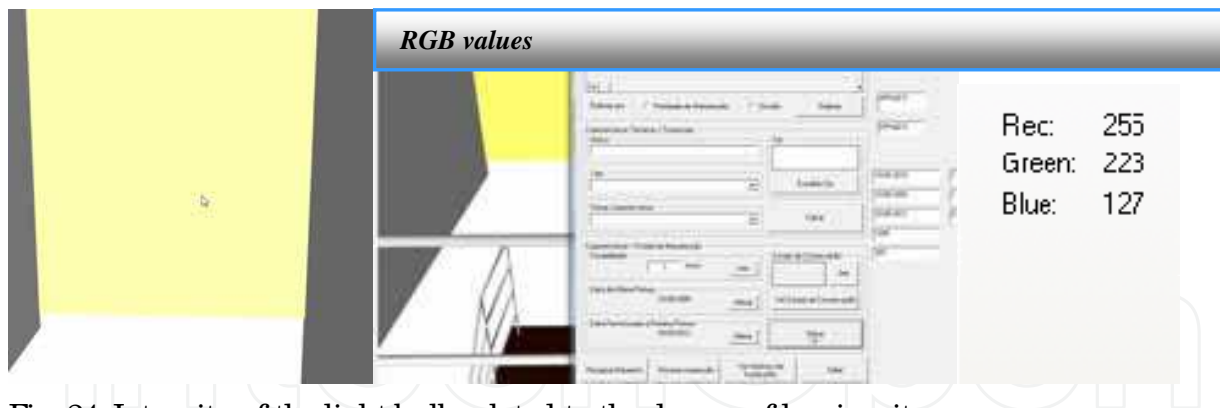
Fig. 24. Intensity of the light bulb related to the degree of luminosity.

amount of elements concerning the lighting system. The 3D geometric model is usually created by an architect. The link between the 3D model and the management prototype is defined in exactly the same way as the model presented in this paper was.

Bulbs monitored remotely: Because the model has a user-friendly interface it can be used by any manager, who can interact with the model in order to select elements from the building and update the associated information. The system supports the management of stocks for each type of bulb and alerts to the planning of local visits. Additionally, each lamp can be monitored remotely. For that a sensor must be fixed to each real lamp and connected to the virtual model. In this way any anomaly (deficient functionality or rupture) is transmitted to the virtual model, and the manager is alerted to the occurrence. In a building with large quantity of elements to be monitored the developed prototype is an important support in management.

5. Conclusions

It has been demonstrated, through the examples presented here, how the technology of virtual reality can be used in the elaboration of teaching material of educational interest in the area of construction processes and to give capacities to students to manage a new technology that can support later there engineering activity. The advantage of introducing new technologies into the creation of didactic material suitable for university students and technical instruction should be made known and applied. It was also focused the importance of teaching CAD systems at school, not only as a good executer of "drawings" but mostly as an helpful tool to be use to develop research work and, as a professional support in there activity as engineers, and also with the VR technology.

The three first applications represent standard situations of constructions. The student can interact with the virtual models in such a way that he can set in motion the construction sequence demanded by actual construction work, observe the methodology applied, analyze in detail every component of the work and the equipment needed to support the construction process and observe how the different pieces of a construction element mesh with each other and become incorporated into the model. The VR technology was also applied to a roof model in order to create an educational application of interest to the teaching of CAD. The issue involved requires three-dimensional location of drawing elements which, in traditional methods of teaching, are putted out using only the horizontal projection. This application supports the explanation of topics related to the construction of both simple roofs and more complex ones. These models are used in disciplines involving

construction and drawing in courses in Civil Engineering and Architecture. The main objective of the practical application of the didactic models is to support class-based learning. In addition, it can be used in distance training based on e-learning platform technology. The involvement of virtual reality techniques in the development of educational applications brings new perspectives to Engineering education. There are many other possibilities for the creation of computational models mainly where the subject matter is suitable for description along its sequential stages of development. The applications with these characteristics make the advantage of using techniques of virtual reality more self-evident, especially when compared to the simple manipulation of complete models which cannot be broken down. The pedagogical aspects and the technical concepts must be attended on the elaboration of those models.

A virtual model concerning the management of the lighting system of a building was defined. The presented example concerns only one type of element, the illumination devices, but it was found to be efficient in the identification of elements, in the promotion of alerts of inspection and in the management of stock, all activities related to the maintenance and management of a building. The benefits of using the model are identified as: preventive maintenance, application in large buildings and control of the lighting intensity effect over the wall surface. This is an innovative tool that can be used with advantages later in the engineering activity.

6. Acknowledgments

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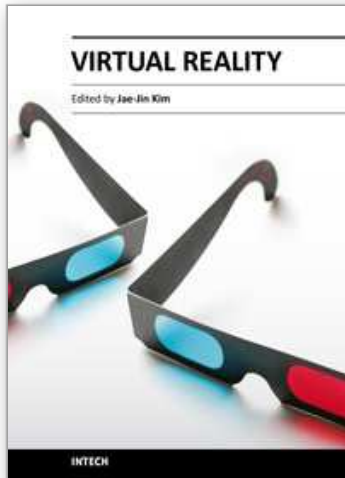
Virtual Reality

Edited by Prof. Jae-Jin Kim

Technological advancement in graphics and other human motion tracking hardware has promoted pushing "virtual reality" closer to "reality" and thus usage of virtual reality has been extended to various fields. The most typical fields for the application of virtual reality are medicine and engineering. The reviews in this book describe the latest virtual reality-related knowledge in these two fields such as: advanced human-computer interaction and virtual reality technologies, evaluation tools for cognition and behavior, medical and surgical treatment, neuroscience and neuro-rehabilitation, assistant tools for overcoming mental illnesses, educational and industrial uses In addition, the considerations for virtual worlds in human society are discussed. This book will serve as a state-of-the-art resource for researchers who are interested in developing a beneficial technology for human society.

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