

VIRTUAL REALITY TECHNOLOGY APPLIED IN CIVIL ENGINEERING EDUCATION: VISUAL SIMULATION OF CONSTRUCTION PROCESSES

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Normally, academic applications of computer-aided design in construction provide a visual presentation of the final state of the project and they are not able to produce changes in the geometry following the construction process. It was developed a didactic prototype that allows physical changes in a building component. This prototype illustrates the construction of common external wall. First, a 3D geometric model composed with the several elements needed to construct it was defined and, then, virtual reality capacities were applied over it. The virtual model allows students to interact with it visualising the sequence of the construction process, accessing to quantitative and qualitative information of each construction stage and observing the configuration details of the building components and how they connect together. The didactic application contributes to support disciplines concerning with Civil Engineering.

Keywords: education, information technology, modelling, simulation, virtual reality.

INTRODUCTION

Normally, academic and commercial applications of computer-aided design in construction, provide a visual presentation of the final state of the project, that is, the three-dimensional (3D) representation of the building with an animated walk-through, allowing observation of both its interior and exterior. Existing educational courseware are not designed follow changes in geometry of the building or structure during the construction process.

The visual simulation of the construction process needs to be able to produce changes to the geometry of the project dynamically. It is also important to extend the usefulness of design information to the construction planning and construction phases (Fischer 2000). The integration of geometrical representations of the building together with scheduling data is the bases of 4D (3D + time) models in construction domain. 4D models combine 3D models with the project timeline (Retik 1997). VTT Building Technology has been developing and implementing applications based on Virtual Reality (VR) technology and 4D to improve construction management practice (Leinonen 2003).

This paper describes a virtual model developed within a research project: *Virtual Reality in optimisation of construction project planning* - POCTI/ 1999/ ECM/36300,

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ICIST/FCT (Henriques 1999) which is now in progress at the Department of Civil Engineering and Architecture of the Technical University of Lisbon. The main aim of the research project is to develop interactive 3D models where students can learn about planning construction activities (Henriques 2002). The innovative contribution lies in the application of VR techniques to the representation of information concerning construction, of practical use to civil construction professionals (Henriques 2003).

As a first step, a prototype serving as a didactic tool for Civil Engineering students of disciplines concerned with building construction was developed. This prototype illustrates a case study of common external wall composed with two brick panels. The virtual model allows the user to visualise the construction component by:

- Interacting with the construction sequence by means of the production of 3D models of the building in parallel with the phases of construction;
- Accessing qualitative and quantitative information on the status of the evolution of the construction;
- Visualising any geometric aspect presented by the several components of the wall and the way they connect together to form the complete wall.

The virtual model also allows students to learn about construction planning of the specific situation presented. This model is oriented to teaching construction techniques by means of virtual environments. It is expected that this model will be able to contribute to support teaching disciplines concerned with Civil Engineering. Another objective in creating this kind of virtual applications is to show in which way new technologies afford fresh perspectives for the development of new tools in the training of construction processes. The virtual models can be very useful both in face-to-face classes and in distance learning using *e-learning* technology.

VIRTUAL REALITY TECHNOLOGY

Virtual Reality can be described as a set of technologies, which, based on the use of computers, simulates an existing reality or a projected reality (Burdea 2003). This technology allows computer users to interact in a 3-d world, e.g. making it possible for them to interact with virtual objects at levels until now unknown in information technology: turning handles to open doors; switching lights on and off; driving a prototype car or moving objects in a house. To achieve this, elements of video, audio and 3D modelling are integrated in order to generate reality, initially through specific peripheral devices (handles, helmets and gloves) and at present, through the Internet. Its origin is attributed to flight simulators developed about fifty years ago by the United States Army. The beginning of VR is attributed to Ivan Sutherland, with the introduction in 1965 of the first 3D immersion helmet, which was later divulged to the peripheral device industry with the designation, head mounted display. A precursor, Nicholas Negroponte (and collaborators), in the seventies, produced a virtual map of guided walks using a model of the city of Aspen, Colorado. In 1989, Jaron Lanier, an important driving force behind this new technology, designated it Virtual Reality (Vince 1998).

Interaction and immersion can be considered the most important characteristics of VR (Vince 1998):

- The immersion sensation is obtained by means of special physical devices, that allow the user to have the sensation of finding himself physically present in a world imagined and modelled by the system;

- The interactive characteristic is assumed because the VR technology is not limited to passive visual representation of this world but enables the user to interact with it (touching or moving objects, for example).

By in addition, the virtual world responds to such actions in real time. In the developed application only the interactive property was explored. Technically, the active participation of the user in a virtual environment, or, in other words, the sensation of immersion or presence in that environment, is achieved on the basis of two factors:

- The integration of information technology techniques (algorithms) used to obtain images of the highest degree of visual realism (ray-tracing, luminosity, application of textures etc.);
- The integration of a series of physical devices resulting from specific technologies like visual technology, sensorial technology (sensors of force and positioning) and mechanical technology (for transmitting movement such as a 3D mouse or gloves).

One of the areas in which the incorporation of VR technology as a means of geometric modelling and visual presentation of 3D animated models is most often applied is Architecture and Engineering. However, VR does not merely constitute a good interface but presents applications that provide the possibility of finding solutions to real problems in such diverse fields as Medicine or Psychology.

METHODOLOGY

As a case study, in the building construction field, an external wall with double brick panels was selected. The developed virtual model allows the student to learn about the construction evolution concerning to an important part of a typical building. The selected construction component focuses on different aspect of the construction process: the structural part, the vertical panels and the opening elements. The 3D geometric model of the wall was defined using the AutoCAD system and transposed to a VR system, based on a programming language oriented to objects, the EON Studio (EON 2003).

Creating the 3D geometric model

All building elements of the wall were identified and defined as 3D objects. Structural elements (demarking the brick panels), vertical panels of the wall and two standard opening elements, were modelled. In order to provide the virtual simulation of the geometric evolution of a wall in construction, the 3D model were defined as a set of individual objects, each one representing a wall component.

Structural elements of the wall

Foundations, columns and beams, were considered as structural elements. The concrete blocks are defined as *box* graphic elements (available in the AutoCAD system) and the steel reinforcements as *cylinder* and *torus* graphic elements. Figure 1 shows some details of these components.

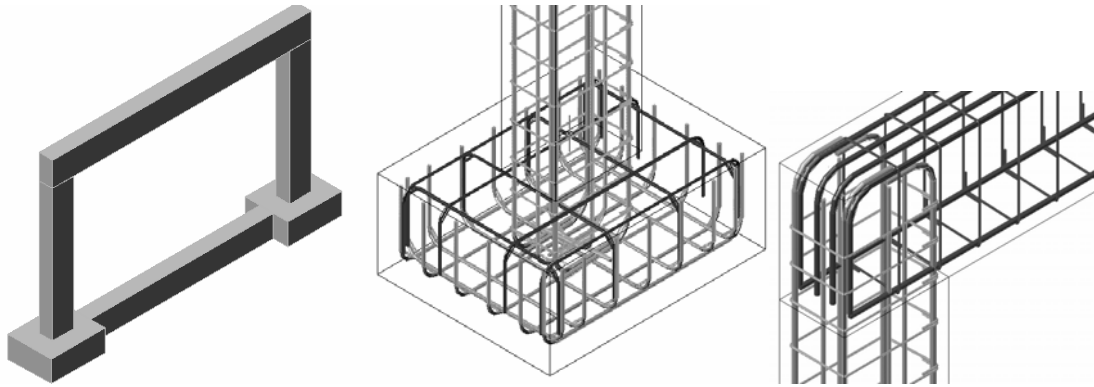


Figure 1 - Details of the structural elements modelled in 3D

In the image, it is possible to observe how to accommodate the steel reinforcements inside the structural elements. This is a real problem that is solved for each case in the work place. The steel elements were modelled taking into account the complexity of there allocation. It is then an illustrative and a didactic example.

Vertical panels of the wall

Confined by the structural elements there are two brick panels and a heating proof layer. Covers all there are two rendering coats and two painted surfaces. Initially, all these elements were modelled as boxes with different thickness. The selection of thickness values for each panel is made according to the usual practice in similar real cases (Figure 2). Next, there were defined openings in the panels to place the window and the door elements.

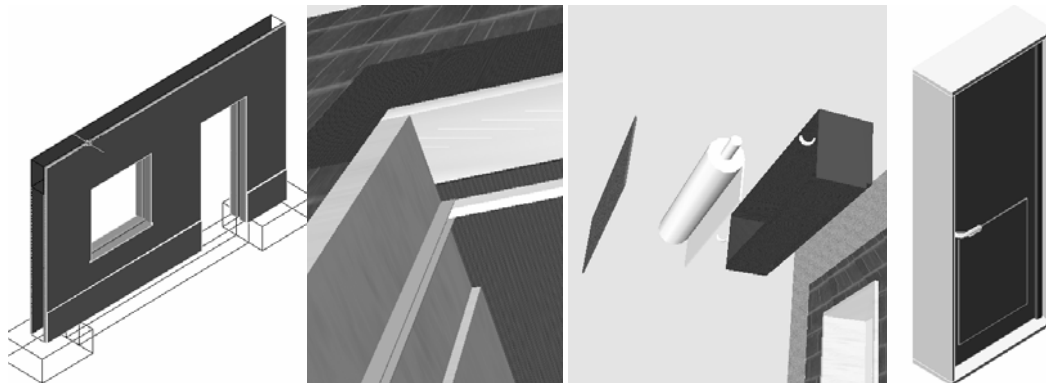


Figure 2 - Details of the wall's vertical and opening components

Opening components of the wall

Finally, the components of two common opening elements, a window and a door, were modelled (Figure 2). The pieces of the window's and the door's frames were created as individual blocks. Each element was modelled taking in consideration the real configuration that such type of elements must present in real situations. By this, at the virtual animation of the wall construction, it is possible to observe each one separately and analyse conveniently the configuration details of those frames.

Creating the virtual environment of the construction process

Each element of the wall is considered as a building component. Figure 3 shows the complete 3D model of the double brick wall. Next, the geometric model was exported as a 3DStudio-drawing file (with the file extension .3ds) to the VR system used, EON Studio (VINCE 1998).

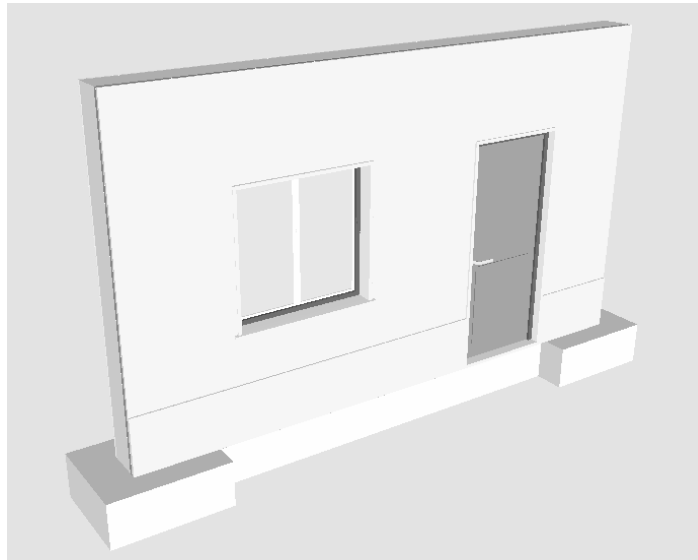


Figure 3 – The complete 3D model of the wall

The VR system should allow the manipulation of the elements of the wall model according to the planning prescribed for the carrying out of the construction. Supporting that, a range of nodes or function is available in the system to build up convenient virtual animations.

Figure 4 presents the work ambience of the EON system. In the left side of the image, is the nodes window (containing the virtual functions available in the system), in the central zone is the simulation tree (is the place where the drawing blocks hierarchy is defined and the actions are imposed to blocks) and, in the right side, the routes simulation window (where the nodes are linked).

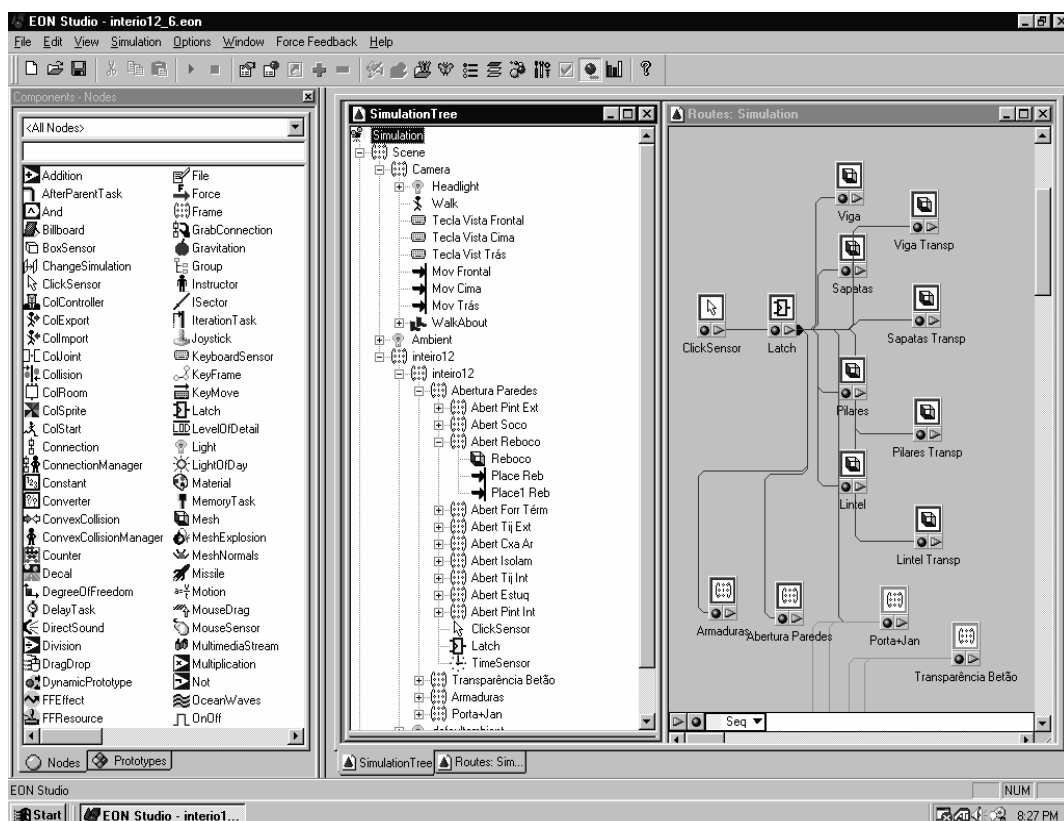


Figure 4 - The work ambience of the EON Studio

When the 3D model is inserted into the VR system, the drawing blocks of the model are identified in the central window. To define an animated presentation the nodes or actions needed are picked from the nodes window and put into the simulation tree. Here, those nodes are associated to the blocks to be affected by the programmed animation.

For instance, to impose a translation to the external rendering coat panel (named “reboco” in the simulation window of Figure 5), two *place* nodes are needed (one to define the place where to go and the other to bring back to its original position). The *ClickSensor* and *Latch* nodes allow the initialization of a programmed action. For that the user interacts with the virtual scenario pressing on a mouse button.

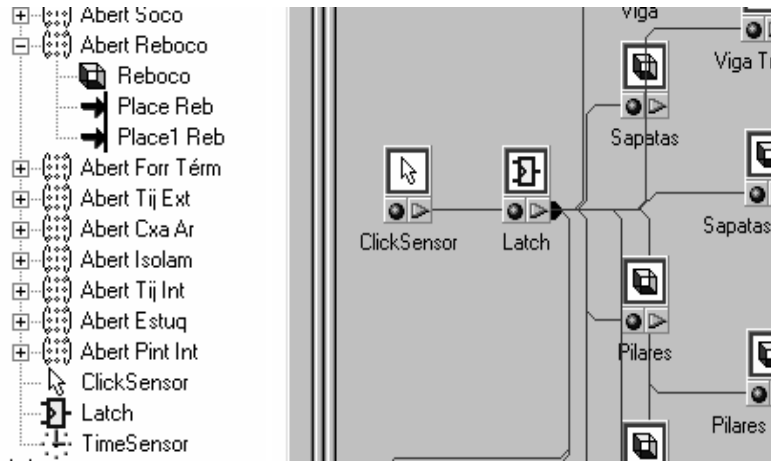


Figure 5 - Aspects of the simulation tree and the routes windows

Vertical panels presented in explosion

The exhibition of the several vertical panels of the wall presented in explosion is a kind of animation with a great didactic interest. Figure 6 includes two steps of this presentation, the opened and closed situations. The translation displacement value attributed to each panel was distinct from each other in order to obtain an adequate explosion presentation.

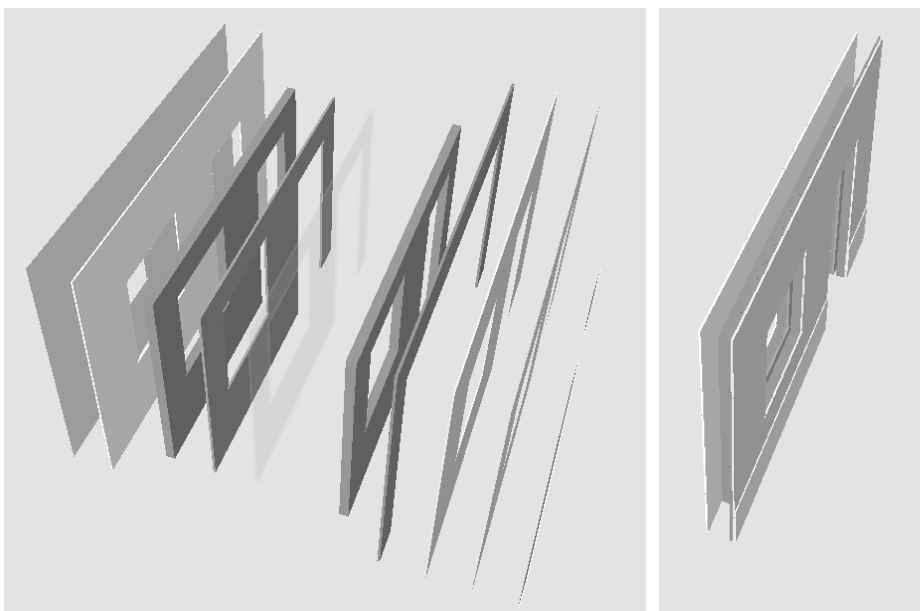


Figure 6 - Vertical panels presented in explosion

This type of animation allows the student to understand the correct sequence of the vertical panels in a wall and to observe the different thickness of each one.

Animation of the wall's construction

The construction process was decomposed in 23 phases following the real execution of this kind of building component, in the work *in loco*. The first element to become visible, at the virtual scenario, is the steel reinforcement of the foundation (Figure 7) and the last is the door pull. The programmed animation simulates the progression of the wall construction. In each step the correspondent 3D geometric model is shown (Figure 7). In this way, the virtual model simulates the changes that really occur while the wall is in construction in a real work place.

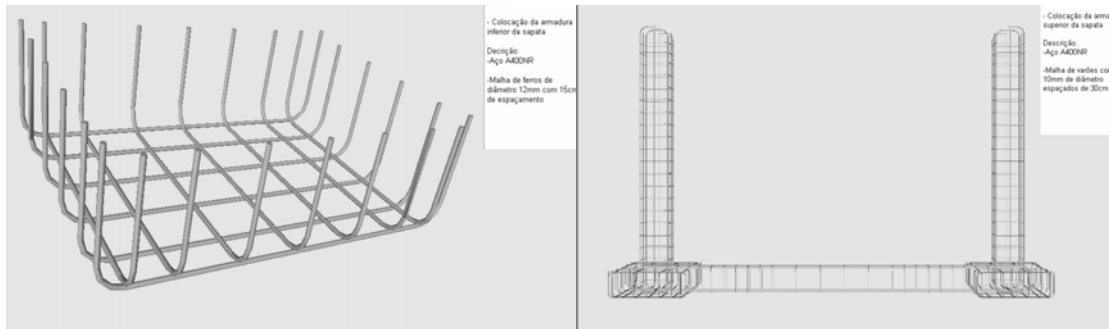


Figure 7 - Presentations of two steps of the virtual construction progress

For each new wall component becoming visible in a construction phase, the virtual model allows the user to pick the element and to manipulate the camera around it (Figure 8). The user can then observe the element (displaced from the global model of the wall) from any point of view. Then all configuration details that the components of a real wall must present can be observed and analysed. This capacity is important in construction process training.

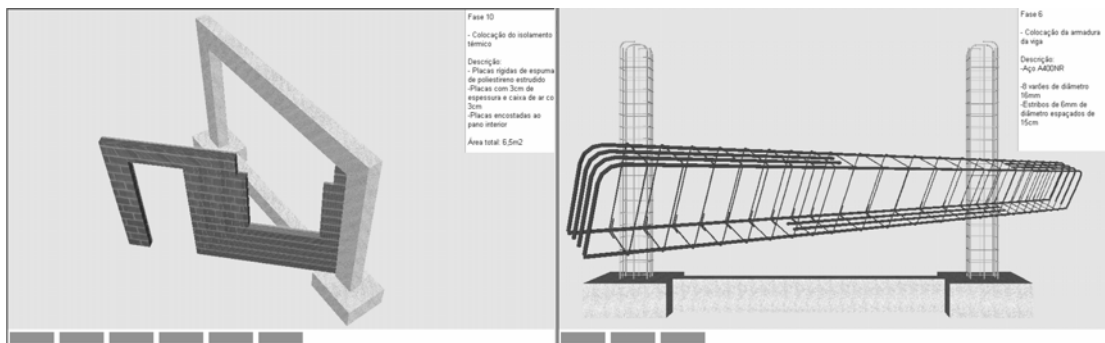


Figure 8 - Pictures presenting elements displaced from the global model of the wall and the box text construction data

While the animation is in progress, a box text is presented, fixed at the upper right corner of the display (Figure 8). It contains construction information about the step in exhibition. The text includes the order number in the sequence, the activity description and the material specification and quantification concerned to each phase. The visualization of this type of data following the virtual construction evolution is useful to students.

The virtual animation presents, below the visualization area, a toolbar (Figure 9). The set of small rectangles included in it shows the percentage, in relation to the wall fully constructed, up to the step visualized. To exhibit the next phase the user must click in

any part of the model. To go back to an anterior step the user must click over the pretended rectangle in that progression toolbar.

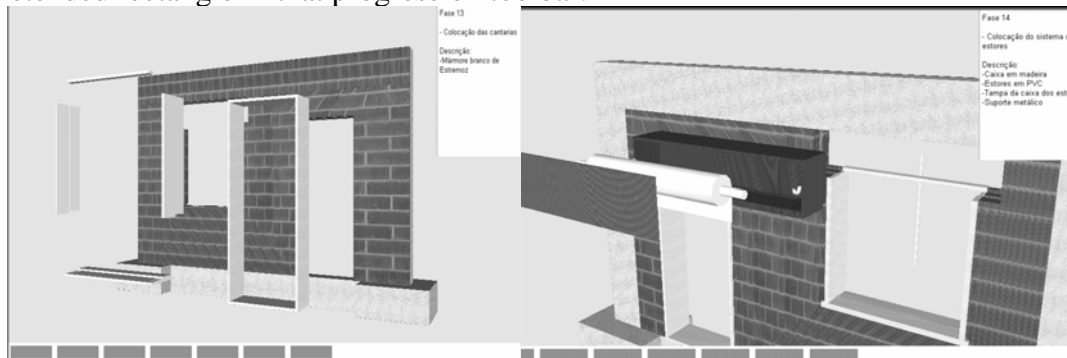


Figure 9 - Images showing the progression toolbar and wall components presented in explosion

Finally, the animation allows the user to visualize the pieces of wall elements in an exploded exhibition. The images included in Figure 9 shows two elements presented in explosion. This type of presentation allows the student to know how the different parts connect each other to form wall components and can observe the configuration of those parts with detail. This capacity provided by the virtual model is also of great interest in construction domain instruction.

FUTURE PERSPECTIVES

Other type of building components can be modelled and manipulated in a virtual scenario for construction learning proposes.

Two other applications, also in the construction area, are now in progress. One concerns to the construction of a bridge by the segmental free cantilever method and the other to the construction of different cases of roofs. With this type of virtual models students can learn about construction technologies and analyses the sequence of construction, the steps required along the correspondent planned execution process and the configuration detail of each element.

LEARNING ASPECTS

The model is actually used in face-to-face classes of two disciplines of the Civil Engineering curricula: Technical Drawing (1st year) and Construction Process (4th year). The teacher interacts with the model showing the sequence construction and the constitution of the modelled building element. As in Technical Drawing, students have to define and represent structural plants using architectural drawings, they better understand the relations between the architectural configurations and the structural elements in a building, following the exhibition of the wall's construction. In Construction Process, in order to prepare students to visit real work places, the teacher shows the construction animation and explains some aspects of the construction process that in the work place they are going to see. Essentially, the model is used to introduce new subjects. The students reflected on their evaluation works a better understanding of subjects concerning structures and construction.

The model was inserted in the site of those disciplines <http://www.ist.utl.pt/pt/ensino/>. The students can then also interact with the model. This type of didactic material can be used also in distance learning based on *e-learning* technology.

CONCLUSIONS

The VR technology applied to construction field made possible to represent a three-dimensional space realistically. The visual simulation of the construction evolution of a common case was achieved. The user can interact with the virtual model of the wall and impose any sequence time in the construction process, select from the wall's model any component or parts of element and manipulate the camera as desire in order to observe conveniently any detail of the components configuration. While the animation is in process, the construction information associated to each step is listed. The use of these capacities, allowed by the developed virtual model, is beneficial to Civil Engineering student in construction process subjects.

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REFERENCES

- Fischer, M. (2000) 4D CAD - 3D Models Incorporated with Time Schedule. *In: CIFE in Finland, VTT-TEKES*, Helsinki, Finland.
- Retik, A. (1997) Planning and monitoring of construction projects using virtual reality projects. *In: Project Management Journal*, 3(97), 28–4.
- Leinonen, J., Kähkönen, K. and Retik, A. (2003). New construction management practice based on the virtual reality technology. *In: Raja R.A., Flood I, William J, O'Brien (Ed.) 4D CAD and Visualization in Construction: Developments and Applications*, A.A. Balkema Publishers, 75-25.
- Henriques, P.G. and Sampaio, A.Z. (1999) *Project Program: Virtual Reality in Optimisation of Construction Project Planning*. POCTI/1999/ECM/36300, ICIST/FCT, Lisbon, Portugal.
- Henriques, P.G. and Sampaio, A.Z. (2002) Visual Simulation in Building Construction Planning. *In: 4th European Conference on Product and Process Modelling*, 9-11 September 2002, Portoroz, Slovenia, 209-5.
- Henriques, P.G. and Sampaio, A.Z. (2003) Interactive project planning in construction based on virtual reality technology. *In: IKM – 16th International Conference on the Applications of Computer Science and Mathematics in Architecture and Civil Engineering*, 10-12 June 2003, Bauhaus-Universität, Weimar, 6.
- Burdea, G and Coiffet, P (2003) *Virtual Reality technology*. 2ed. John Wesley & Sons.
- Vince, J (1998) *Virtual Reality Systems*, ACM SIGGRAPH Books series, Addison-Wesley.
- EON (2003) *Introduction to Working in EON Studio*, EON Reality, Inc.