

LEARNING CONSTRUCTION PROCESSES USING VIRTUAL REALITY MODELS

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SUMMARY: 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 a 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, 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: visual tools, visual simulation, construction process, computer-aided design.

1. 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 to follow changes in the geometry of the building or the structure during the construction process.

The visual simulation of the construction process needs to be able to produce geometric changes of the project dynamically. It is also important to extend the usefulness of design data to the construction planning. 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 et al, 2003).

The virtual model presented here was developed within the activities of a research work: *Virtual Reality in optimization of construction project planning* – POCTI/1999/ECM/36300, ICIST/FCT (Henriques, 1999) 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 three-dimensional models where students can learn about planning construction activities by means of the visual simulation of its development. The innovative contribution lies in the application of VR techniques on the representation of geometric evolution of a construction and data concerning it (Henriques and Sampaio, 2003, Sampaio et al, 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 the construction of a common external wall composed with two brick panels. The virtual model allows the user to visualise the construction components by:

- Interacting with the construction sequence by means of producing 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 process;
- 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 allows students to learn about construction planning concerned to this specific situation. This model is oriented to support teaching construction techniques by means of virtual environments. This model is now shown in classes and it contributes to a better understanding of disciplines concerning 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. Visual interaction can do some changes in the way engineering education is performed, both in learning new materials and in terms of explaining construction activities (Sulbaran et al, 2000). Normally, very little visual information is presented in engineering schools: students mainly listen to lectures and read material written (Felder et al, 1988). But, most of the students are visual learners, so the visual interactive model is a interesting didactic tool.

The virtual models can be very useful both in face-to-face classes and in distance learning using *e-learning* technology. VR provides opportunities to deliver technical education in ways not possible through traditional methods, thereby broadening the range of tools available to modern educators, in order to reach more students and subjects (Bell et al, 2004).

2. VIRTUAL REALITY TECHNOLOGY

2.1 Concept and historical background

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 and Coiffet, 2003). This tool allows computer-users to be placed in three-dimensional worlds, 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 three-dimensional modeling are integrated in order to generate reality, initially through specific peripheral devices (handles, helmets and gloves).

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 three-dimensional 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 70's, 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 emerging technology, designated it *Virtual Reality* (Vince, 1998).

In the 90s, with the upsurge of the Internet, a specific programming language was defined, the Virtual Reality Modeling Language (VRML). It is a three-dimensional interactive language devised for the purpose of modeling and visually representing objects, situations and virtual worlds on the Internet, which makes use of mathematical co-ordinates to create objects in space (Burdea and Coiffet, 2003). This constitutes a new means of communication that allows the construction of, and experimentation with, new computer-modeled realities.

2.2 Principal technological characteristics of Virtual Reality systems

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 an imagined world modeled by the system;
- The interactive characteristic is assumed because the Virtual Reality 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).

What is more, the virtual world responds to such actions in real time. In the developed application only the interactive propriety 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 modeling and visual presentation of three-dimensional animated models is most often applied is Architecture and Engineering (FIG. 1). The range of potential applications extends from buildings on a small scale to the development of town plans. However, VR technology 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 Engineering, Medicine or Psychology.

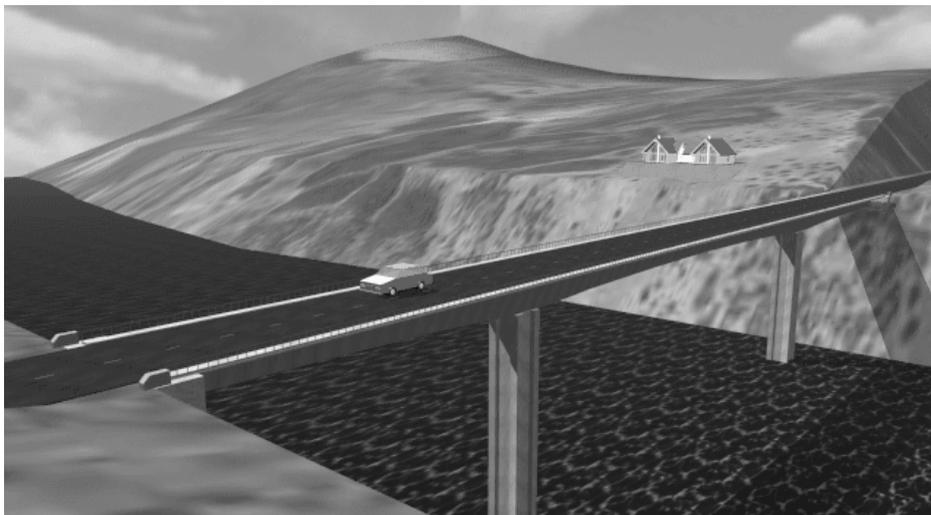


FIG. 1: A three-dimensional model of a bridge.

3. THE WALL VIRTUAL MODEL

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).

3.1 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.

3.1.1 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). The FIG. 3 shows some details of these components.

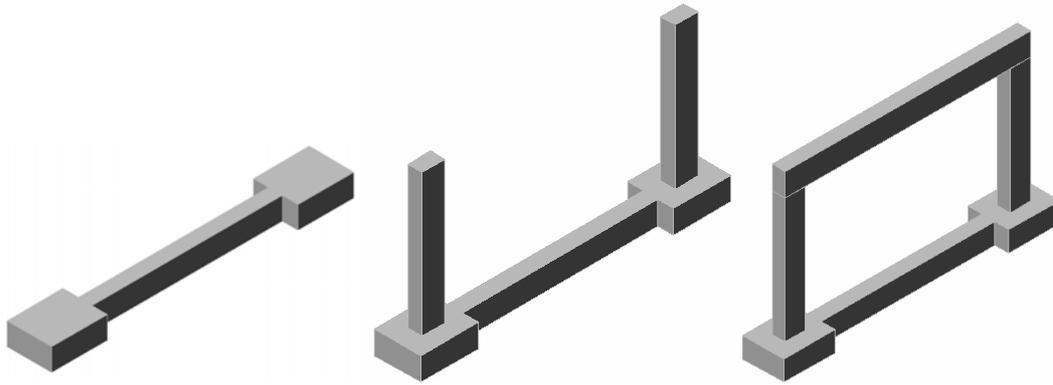


FIG. 2: Details of the structural elements of the wall's 3D model.

The steel reinforcements were modeled as *cylinder* and *torus* graphic elements. In FIG. 3, 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 their allocation. It is then an illustrative and a didactic example.

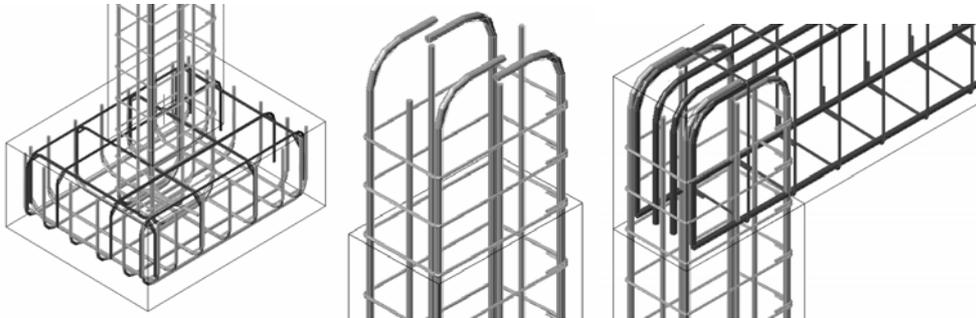


FIG. 3: Details of the steel reinforcements located inside the structural elements.

3.1.2 Vertical panels of the wall

Confined by the structural elements are two brick panels, a heating proof layer, two rendering coats and two painted surfaces. Initially, all these elements were modeled as boxes with different thickness. The selection of thickness values for each panel is made according to the usual practice in similar real cases. Next, there were defined openings in the panels to place the window and the door elements as shown in FIG. 4.

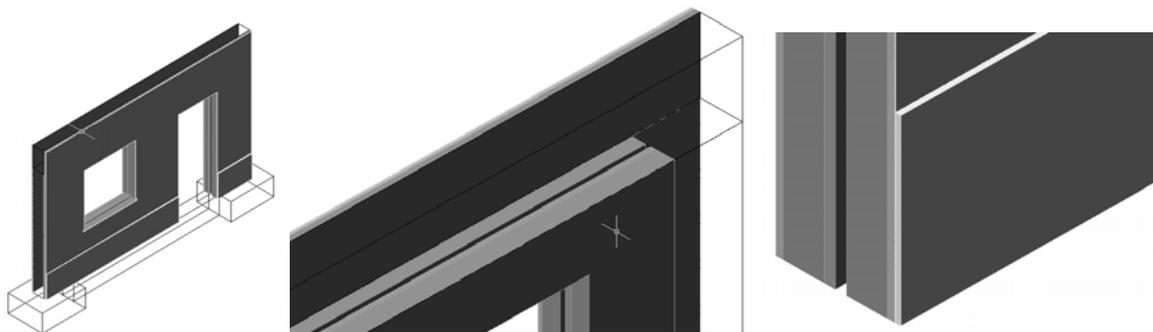


FIG. 4: Details of the vertical panels of the 3D model.

3.1.3 Opening components of the wall

Finally, the components of two common opening elements, a window and a door, were modeled (FIG. 5). The pieces of the window's and the door's frames were created as individual blocks. Each element was modeled taking into consideration the real configuration that such elements must present in real situations.

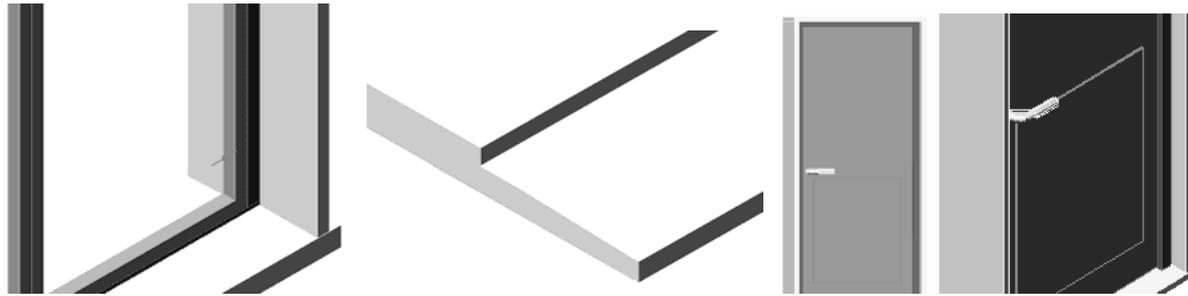


FIG. 5: Details of the window and the door elements.

At the virtual animation of the wall construction, it is then possible to observe each one separately, and analyse conveniently the configuration details of those frames and how they connected together.

3.2 Application of Virtual Reality capacities

One by one every part of each element considered as a building component of the wall was modeled. FIG. 6 shows the complete wall model. Next, the 3D model was exported as a 3DStudio-drawing file (with the file extension .3DS) to the VR system used, *EON Studio* (EON, 2001).

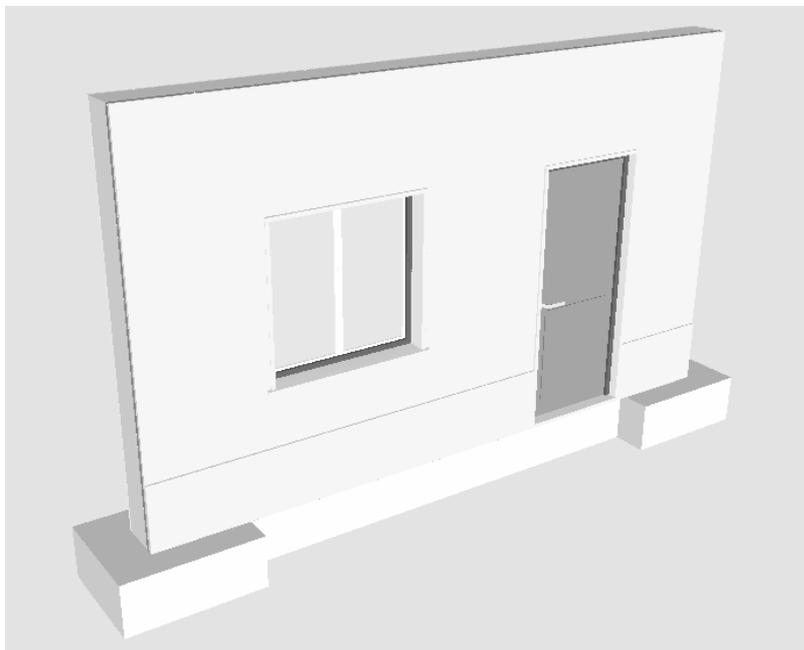


FIG. 6: Projection of the developed 3D models of the wall.

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

FIG. 7 presents the work environment of the *EON Studio*. On the left side of the image, is placed the nodes window (containing the virtual functions available in the system), in the central window is the simulation tree (the place where the drawing blocks hierarchy is defined and the actions are imposed to blocks) and, on the right side, the routes simulation window (the module where the nodes are linked). Essentially, the simulation is programmed using the last two windows.

When the wall model is inserted into the virtual system, the drawing blocks of the model are visualized in the central window. To programme 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 with the blocks to be affected by the programmed animation.

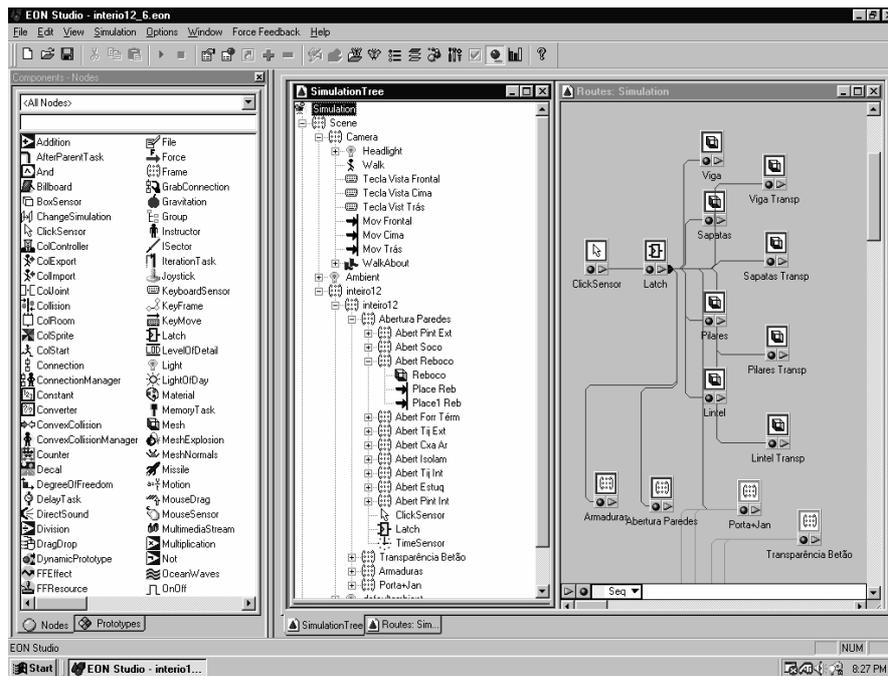


FIG. 7: The work ambience of the EON system.

3.2.1 Animation of vertical panels presented in explosion

The exhibition of the several vertical panels of the wall in explosion is an interesting didactic representation. FIG. 8 includes two steps of this animation, 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. 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.

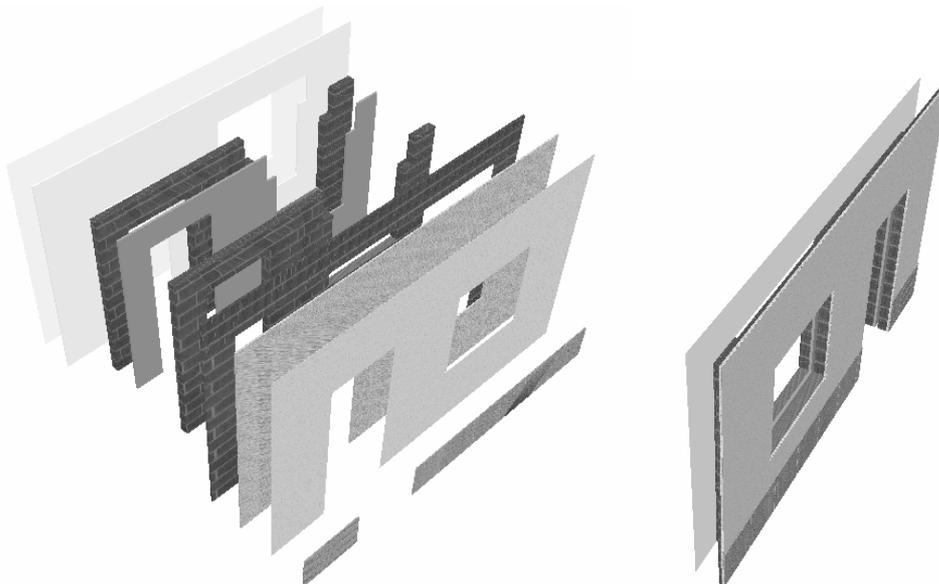


FIG. 8: Presentation in explosion of the vertical panels of the wall model.

3.2.2 Presentation of the structural elements with a transparency appearance

It was programmed an animation allowing the visualization of the steel reinforcements inside the structural elements (FIG. 9). For that, in the virtual environment, the surface texture of the structural elements changes from opaque to a transparent appearance (with a low degree of opacity). Using the virtual model is then possible

to observe the standard distances that must be provided between the surface of the structural elements and the steel reinforcements. It is also possible to study how these steel elements are accommodated inside the concrete boxes. As a didactic tool it is important that the model can allow the analyses of this kind of constructive details.

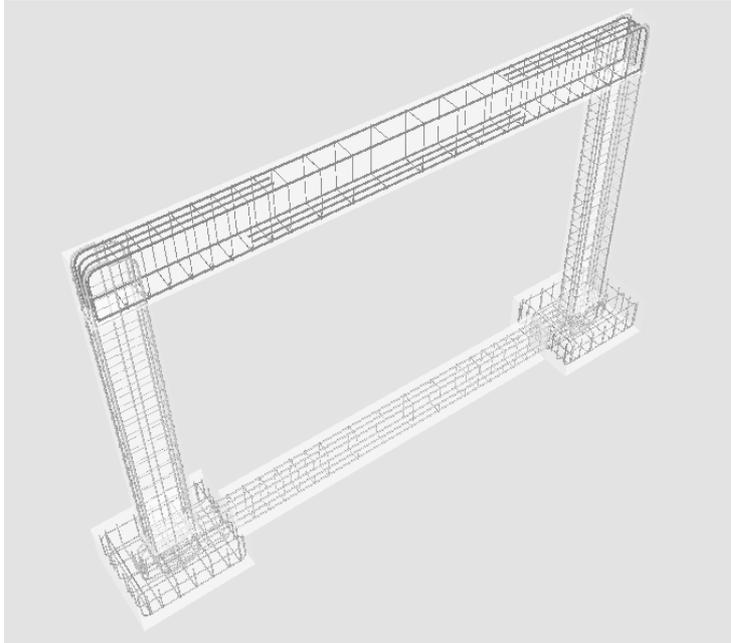


FIG. 9: Presentations of the structural elements with a transparent appearance.

3.2.3 Interaction with the construction process sequence

The construction process was decomposed in 23 phases following the real execution of this kind of element in the work place. The first element to become visible, in the virtual scenario, is the steel reinforcement of the foundation (FIG. 10) and the last is the door pull.

The programmed animation simulates the progression of the wall construction. For each construction step the correspondent geometric model is shown (FIG. 10). In this way, the virtual model simulates the changes that really occur while the wall is in construction in a real work place.

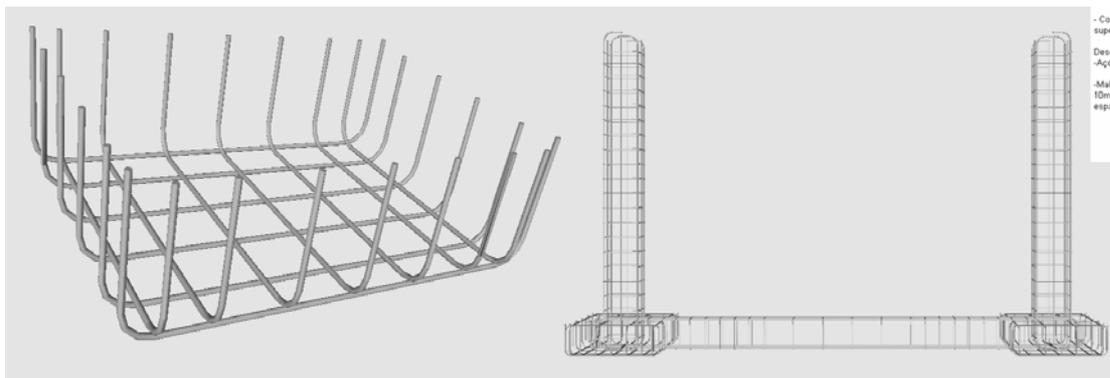


FIG. 10: Presentations of two steps of the virtual construction progress.

By manipulating the camera with zooms over the model, all configuration details that the components of a real wall must present can be observed and analyzed. FIG. 11 shows details of a window's element and the relative positions between structural elements (presented in transparency) and vertical panels of the wall. This capacity is important in construction process training.

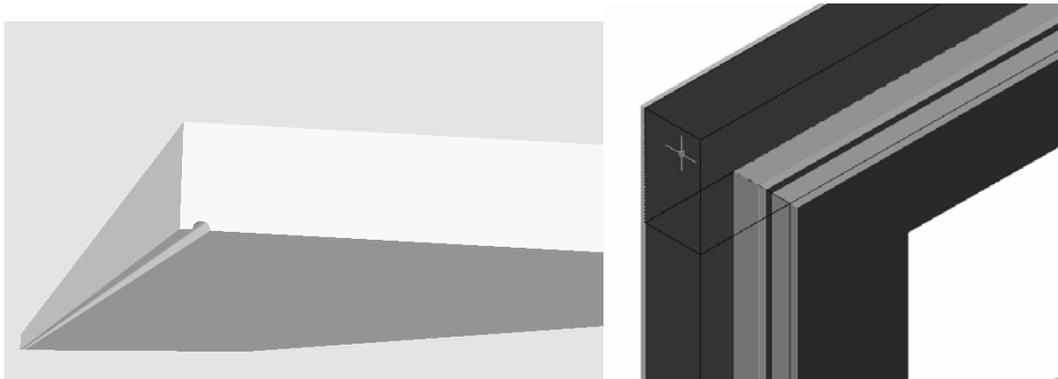


FIG. 11: Pictures presenting details of the wall components.

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 (FIG. 12:). The student can then observe the element (displaced from the global model of the wall) from any point of view.

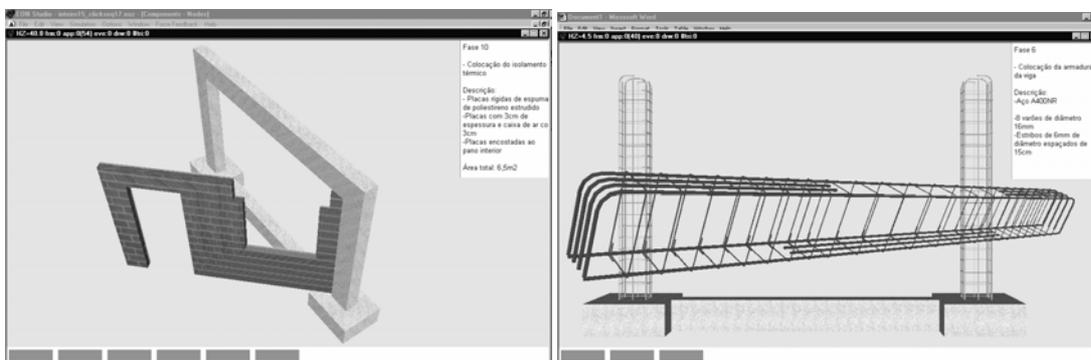


FIG. 12: Pictures presenting elements displaced from the global model of the wall.

While the animation is in progress, a box text is presented, fixed at the upper right corner of the display (FIG. 13). It contains construction information about the step in exhibition. The text includes the number, 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.

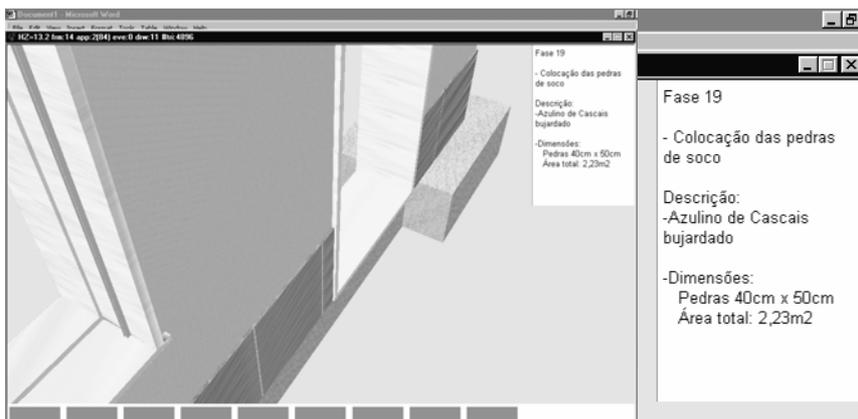


FIG. 13: Picture presenting the box text with construction information.

The virtual animation presents, below the visualization area, a toolbar (FIG. 14). The set of small rectangles included in it shows the percentage of construction 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 corresponding rectangle in that progression toolbar.

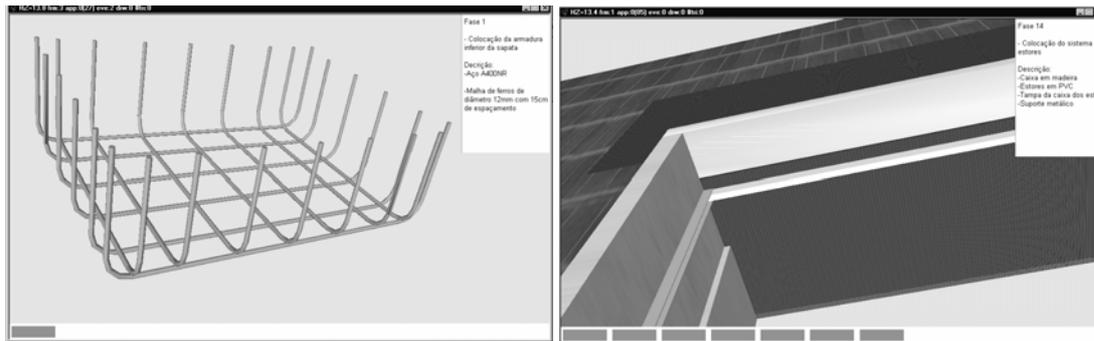


FIG. 14: Different aspect of the toolbar concerning to two steps.

Finally, the animation allows the user to visualize the pieces of the wall elements in an exploded exhibition. The images included in FIG. 15 show two elements presented in explosion. This type of presentation allows the student to know how the different parts connect together in the wall and can observe the configuration of those parts with detail.

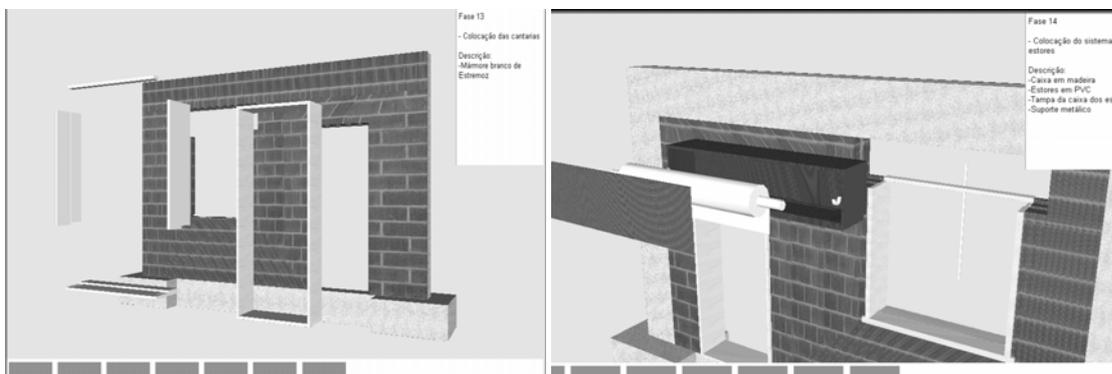


FIG. 15: Images presenting components of the wall in explosion.

4. LEARNING ASPECTS

The model is actually used in face-to-face classes of two disciplines of Civil Engineering curriculum: 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. For instance, in a structural plant the representation of columns and beams is now better aligned. Or, the students' reports concerning visits at work places include now some aspects shown in the virtual model.

The students can also interact with the model. For that, the model was inserted in the site of those disciplines <http://www.ist.utl.pt/pt/ensino/>.

5. 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 (Sampaio et al, 2004) and the other to the construction of different cases of roofs. With this type of virtual models students can learn about construction technologies while

observing the sequence of a construction case, the steps required along the correspondent planned execution process, the configuration details of each element and how the work equipment operates along the construction.

The main objective of this kind of didactic models is to show in an easy way and as complete in details as possible several constructive processes. Using these models students can learn about construction technologies and analyze the sequence of construction, the steps required along the correspondent planned execution process, the configuration detail of each element and different strategies in construction planning.

6. 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 virtual model, is beneficial to Civil Engineering student in construction process subjects.

7. ACKNOWLEDGEMENTS

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