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A Virtual Reality Tool in Civil Engineering Education

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ABSTRACT: *The usual academic and commercial CAD systems in construction design, only allow the visualization of the final stage of the project, namely, as building three-dimensional (3D) models and walk-through (by its inside and outside). Current computer tools and models are not able to follow changes in the geometry of a building or structure during the construction process.*

A Virtual Reality technology application in the construction-training domain is described. A prototype was developed. It serves as a didactic tool for civil engineering students of disciplines concerned with building's construction. Geometric Modelling and Virtual Reality techniques are used on the visual simulation of construction processes and to define user-friendly interfaces in order to access construction information, which could prove useful to civil engineering professionals. The construction of a double brick wall is the case studied. The wall is defined as a 3D geometric model formed with the several components needed to construct it. Using the wall's virtual model it is possible to show, in an interactive way, the sequence of the construction process and observe, from any point of view, the configurations in detail of the building components. This is a didactic application in the construction processes domain of great interest to civil engineering students.

So, using the developed virtual model, allows students to learn about construction planning of a specific situation in the space provided by the virtual environment. This communication is then oriented to teaching construction techniques by means of virtual environments. It is expected that the implementation of the prototype will be able to contribute to support teaching disciplines concerned with Civil Engineering. Another objective in creating these 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.

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. The current computer tools and models are unable to follow changes in the 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. Is then 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).

The virtual model presented here was developed within the activities of a research work: *Virtual Reality in optimisation 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 3D models where students can learn about planning construction activities. 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 2002, 2003).

As a first step, a prototype serving as a didactic tool for civil engineering students of disciplines concerned with building construction was developed. The study case is a common external wall composed with two brick panels. The wall's virtual model, developed along this work, allows the user to visualize the construction progression, in particular, the following actions:

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

Using the developed virtual model, allows students to learn about construction planning of the specific situation presented. This communication is oriented to teaching construction techniques by means of virtual environments. It is expected 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 in distance learning using *e-learning* technology.

2 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 new tool allows computer-users to be placed in 3D 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 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). In the 90s, with the upsurge of the Internet, a specific programming language was defined, the Virtual Reality Modelling Language (VRML). It is a three-dimensional interactive language devised for the purpose of modelling and visually representing objects, situations and virtual worlds on the Internet, which makes use of mathematical co-ordinates to create objects in space.

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).

What is more, 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.

Write the names of all authors in a required order, always the first name(s) first and then the surname in capital letters. Separate the individual authors by semicolon. If all the authors are from the same organization, do not specify them by numerals. If the authors are from different organizations, use separate paragraphs followed by the author's address.

3 DEVELOPING THE 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 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, a computer-aided drawing system common in Civil Engineering offices. Next, the wall model was 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

First, all building elements of the wall must be identified and defined as 3D models. Structural elements (demarking the brick panels), vertical panels of the wall and two standard opening elements, were modelled. In order to provide, later in a virtual space, the simulation of the geometric evolution of a wall in construction, the 3D model must be 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) and the steel reinforcements as *cylinder* and *torus* graphic elements. The Figure 1 shows some details of these components.

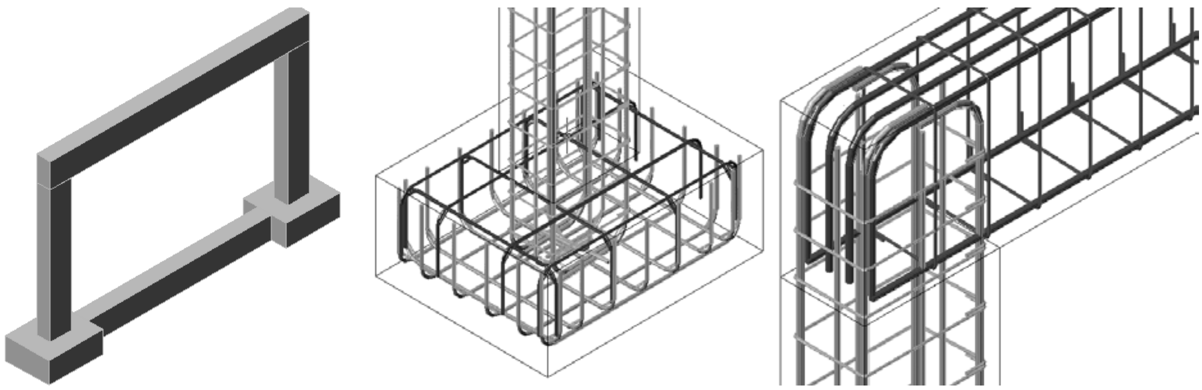

Figure 1 - Details of the structural elements modelled in 3D

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 *in loco*. These elements were modelled taking account this kind of difficulty. So, it is an illustrative example.

3.1.2 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.

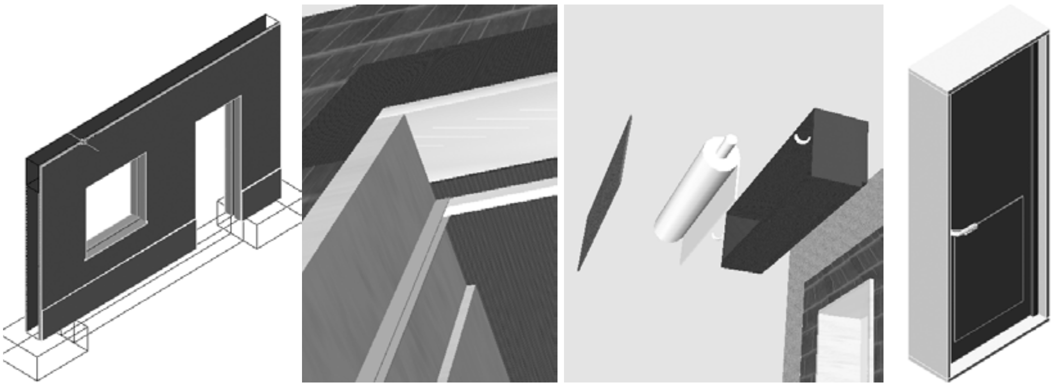

Figure 2 - Details of the wall's vertical and opening components

3.1.3 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.

3.2. Creating the Virtual Environment of the Construction Process

One by one every part of each element considered as a building component of the wall was modelled. The 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).

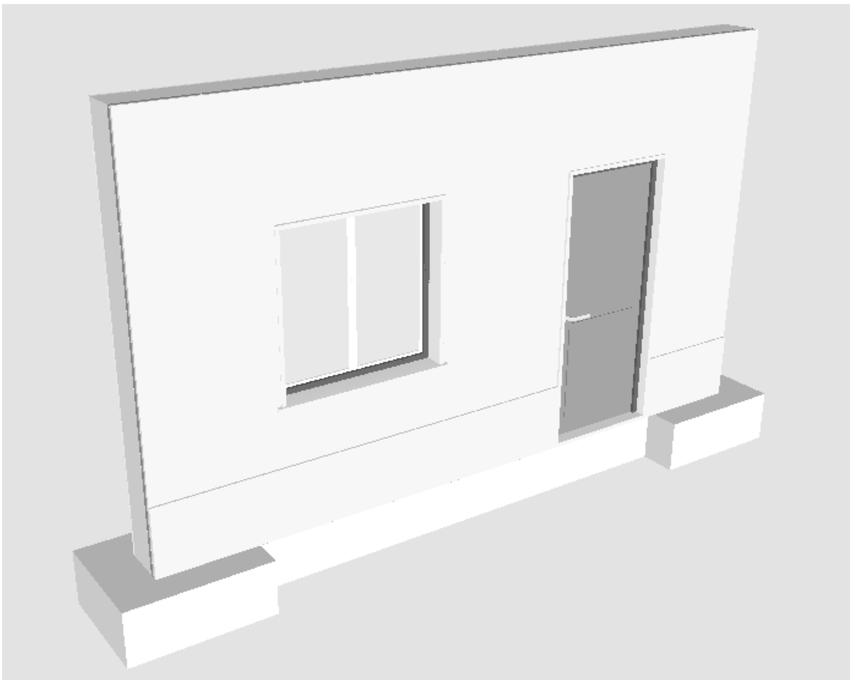

Figure 3 – The complete 3D model of the wall

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.

The 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).

When the 3D model is inserted into the RV 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.

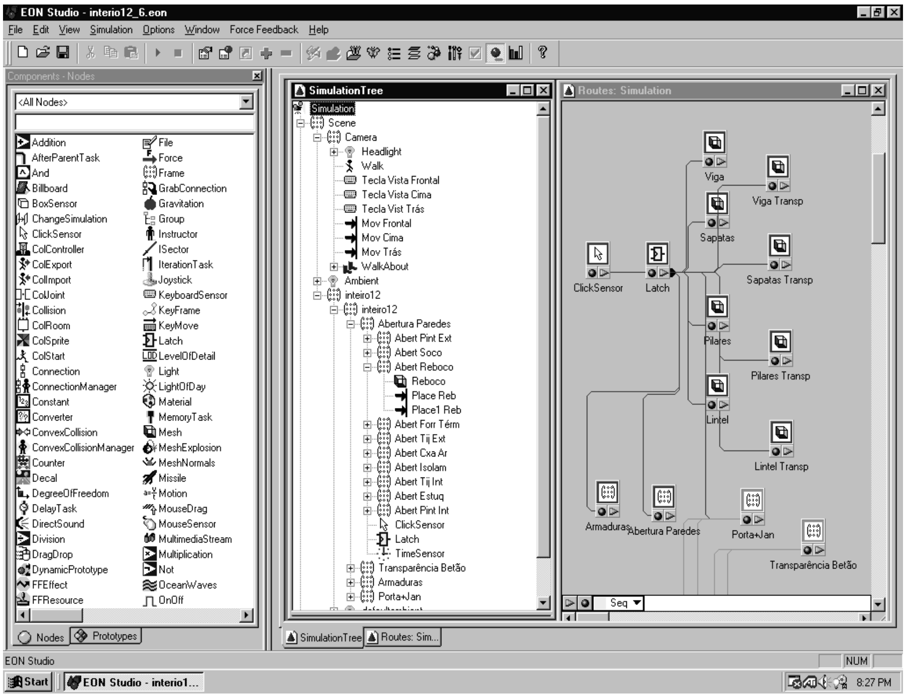

Figure 4 - The work ambience of the EON Studio

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.

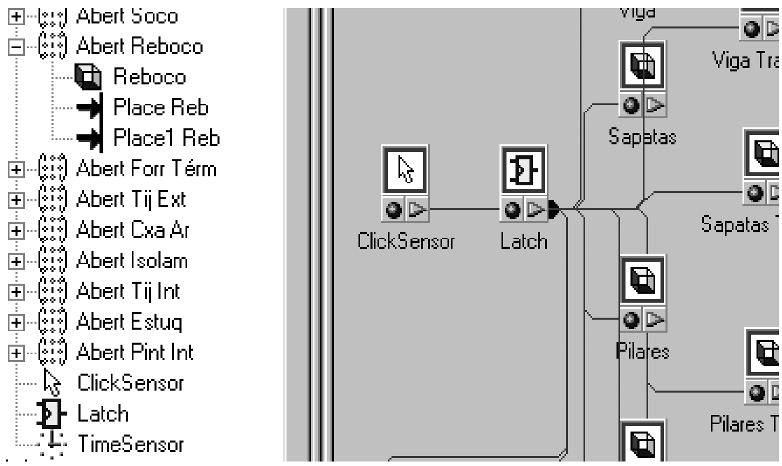

Figure 5 - Aspects of the simulation tree and the routes windows

3.2.1 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. 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.

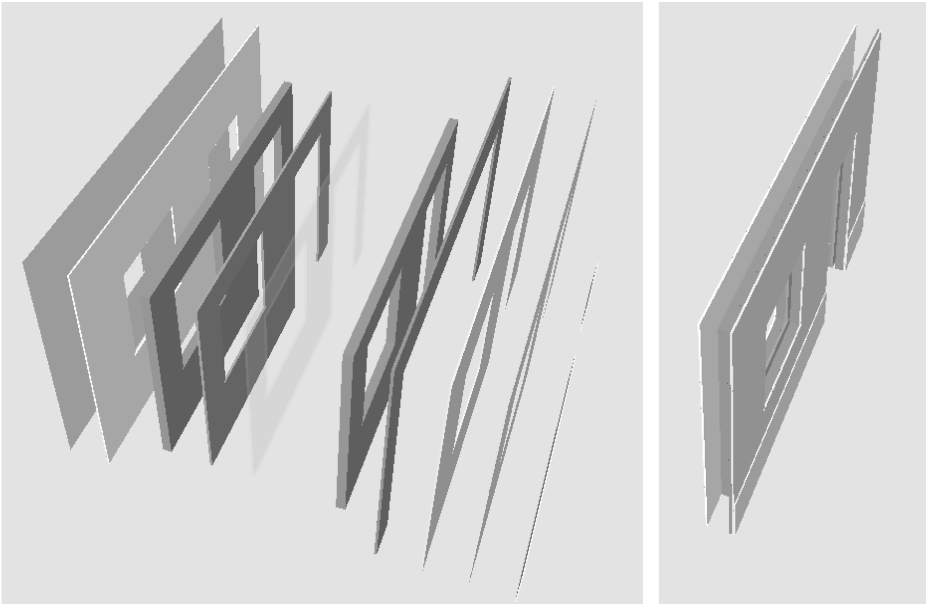

Figure 6 - Vertical panels presented in explosion

3.2.2 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.

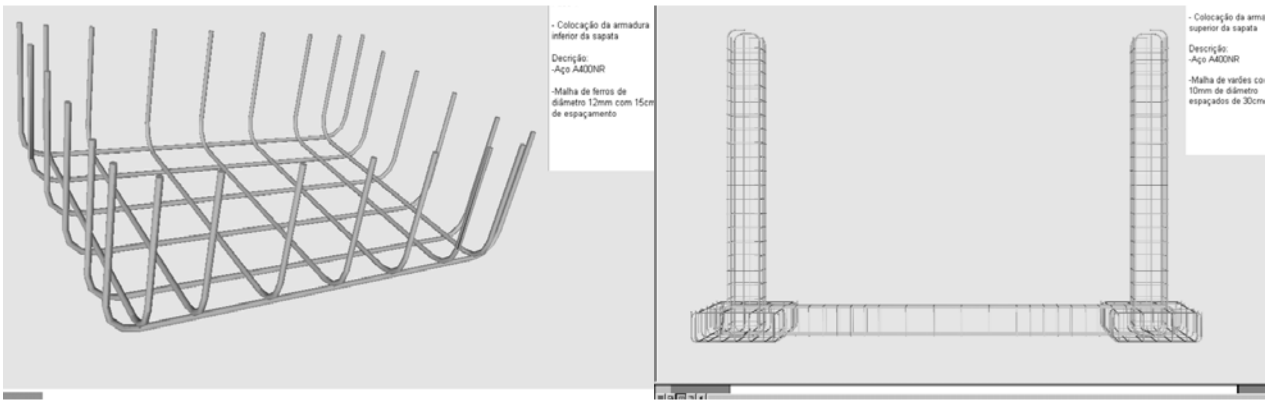

Figure 7 - Presentations of two steps of the virtual construction progress

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.

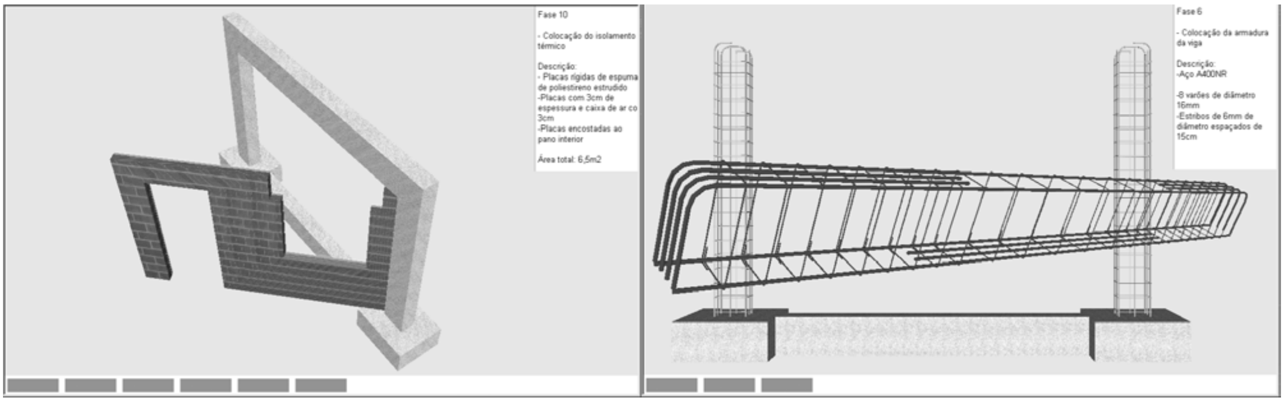

Figure 8 - Pictures presenting elements displaced from the global model of the wall and the box text construction data

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.

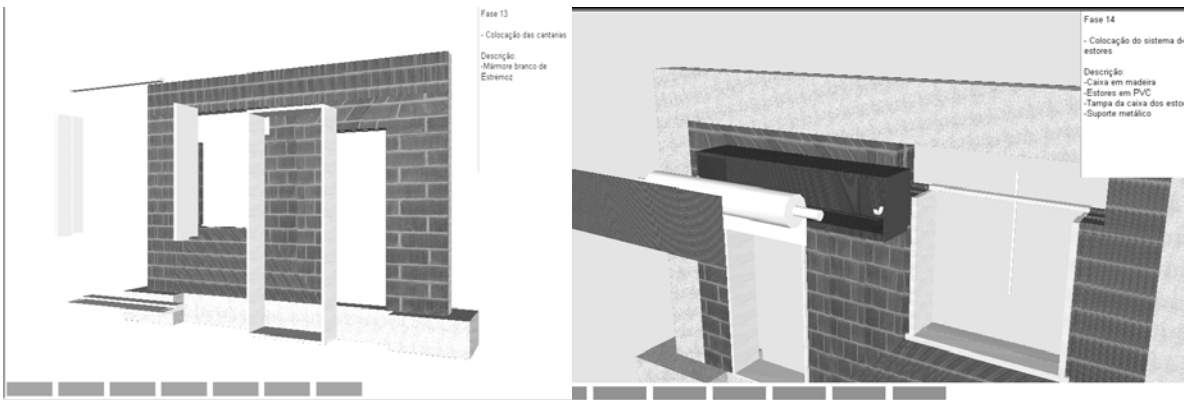

Fig. 9. Images showing the progression toolbar and wall components presented in explosion

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.

This type of didactic material can be used in face-to-face classes and in distance learning based on *e-learning* technology. The insertion of the model in the site of disciplines concerning construction is now in preparation.

4 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.

5 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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