

# Virtual Reality Technology Applied on the Visual Simulation of Construction Activities

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**Abstract:** The three-dimensional geometric models used to present architectural and engineering work, show only the final form, which does not allow progress in constructions to be observed. However, the visual simulation of the construction process of a building need models which are able to produce dynamic changes of its geometry. This paper reports how virtual reality techniques were used to obtain models that could show their physical evolution over time and which would be able to simulate construction processes visually. Two types of construction works were developed as virtual models for educational purposes. These models make it possible: to view the physical evolution of the work; to follow the planned construction sequence; to visualize details of the form of every component of each work; to support the study of the type and method of operation of the equipment necessary in the construction process. Both models have been used to distinct advantage as educational aids in Civil Engineering courses. The use of virtual reality techniques in the development of educational applications brings new perspectives to the teaching of subjects related to the field of construction.

## INTRODUCTION

Normally, three-dimensional (3D) geometric models, which are used to present Architectural and Engineering works, show only their final configuration, not allowing the visual simulation of their physical stages. The models concerning construction needs to be able to produce changes of its geometry. The integration of geometric representations of a building together with scheduling data related to construction planning information is the bases of 4D (3D + time) models (Fisher 2000) [1]. In addition Virtual Reality (VR) technology has been used to turn 4D models more realistic allowing interaction with the environment representing the construction place (Chau JCEM 2004) [2]. VTT Building Technology has been developing and implementing applications based on this technique improving a better communication between the partners in a construction project (Leinonen 2003) [3].

The use of 4D models linked with construction planning software or with virtual and interactive capacities, concerns essentially economic and administrative benefits as a way of presenting the visual simulation of the "real situation" of the work in several financial steps. Those models are created for each particular project and are mostly manipulated by the principal designer or contractor. In another cases they are used to explain complex or innovative construction processes to subcontractors or workers and also to improve job-site communication (Mourgues 2007) [4].

When modeling 3D environments a clear intention of what to show must be planned. That is, the objects to display and the details of each one must be appropriated to the goal the Engineer wants 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 scheduling 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 pedagogical judgments.

Advanced computer based teaching aids regarding 3D models have been introduced into the classroom. Actually this type of new technologies has an important role in teaching activity, during course presentations. How to expose issues concerning complex sequences, physical evolution of a multiple composed body or laboratorial experiences is better supported by visual animated worlds than by standard pictures or scheme. These animations can be videos, walk around or through 3D complete models or, more realistically, interactive virtual models. The application of advanced technology is especially helpful in Civil Engineering disciplines, namely in construction field, concerning new building or renovation of antique or historic buildings (Pentillä 2007) [5]. In other areas is possible to find also examples of virtual simulation like remote physics experiments (Ozvoldiva 2006) [6] and simulated control laboratorial experiences (Watson 2005) [7]. The use of virtual reality techniques in the development of educational applications brings new perspectives to the teaching activity.

As it was reported above, most of the virtual applications used in construction field are helpful to improve communication between partners in a construction project and when used in education they are generally associated with laboratorial or physical experiences. The application context of the two models presented here are quite different from those because they are developed to support teachers to expose actions, realized in a three-dimensional space, but very difficult to explain to students based only on the use of layouts or pictures. So, these VR applications were mainly development to support the exposition of new issues concerning three dimensional actions.

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## DIDACTIC VIRTUAL MODELS

In the present study, two engineering construction work models were created, from which it was possible to obtain 3D models corresponding to different states of building configuration, simulating distinct stages in construction processes (Sampaio 2006) [8]. The developed applications make it possible to show the physical evolution of the work, to allow the monitoring of the planned construction sequence, and to visualize the geometric details of every component of the construction. They also assist the study of the type and method of operation of the equipment necessary for these construction methodologies (Sampaio 2007) [9].

The aim of the practical application of the virtual models is to provide support in Civil Engineering education namely in those disciplines relating to **bridges** and **construction process** both in classroom-based education and in distance learning based on e-learning technology. Expert in construction processes and bridge design were consulted and involved in the creation of the models in order to obtain efficient and accurate didactic applications. The selected examples are two elementary situations of construction works: an **external wall** is a basic component of a building and the cantilever method of **bridge deck** construction is applied frequently.

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;
- Sequence of exhibition to follow;
- Relationship established between the components of both type of construction;
- Degree of geometric details needed to present;
- 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. Specifically:

- The **model of the wall** shows the information concerning construction activity of interest for students corresponding to the geometric stage displayed in each moment;
- The **bridge construction model** shows particularly the movement of the equipment in operation during the progression.

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.

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 virtual activity. The virtual model can be manipulated allowing the teacher or student to monitor the physical evolution of the work and the inherent construction activity. This type of model allows the participant:

- To **interact** in an intuitive manner with the simulated environment;
- To **repeat** the sequence or task until the desired level of proficiency or skill has been achieved;
- 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 the area of Civil Engineering.

## 3D MODEL OF THE WALL

The model of a masonry cavity wall shows a basic component of a standard building. To enable the visual simulation of the construction of the wall, the 3D model is composed of a set of elements, each representing one component of the construction. The selection of elements and the degree of the configuration detail of each component model had the support of teachers and specialist in construction. Using the *EON Reality system* (EON 2003) [10], a system of virtual reality technology, specific properties were applied to the geometric model of the wall in order to obtain a virtual environment. Through direct interaction with the model, it is possible both to monitor the progress of the construction process of the wall and to access information relating to each element, namely, its composition and the phase of execution or assembly of the actual work, and compare it with the planned schedule. This model has been used to distinct advantage as an educational aid in Civil Engineering curriculum.

## GEOMETRIC MODELING OF THE ELEMENTS OF THE CONSTRUCTION ENVIRONMENT

The 3D geometric model of an **exterior wall** is composed of structural elements (foundations, columns and beams), vertical filler panels and two bay elements (door and window). Every element was modeled using the *AutoCAD* system:

- The **structural elements** of the model were created with parallelepipeds and were connected according to their usual placement in building works. Because this is an educational model, the steel reinforcements were also defined. In the model, the rods of the reinforcements are shown as tubular components with circular cross-section (Fig. 1).

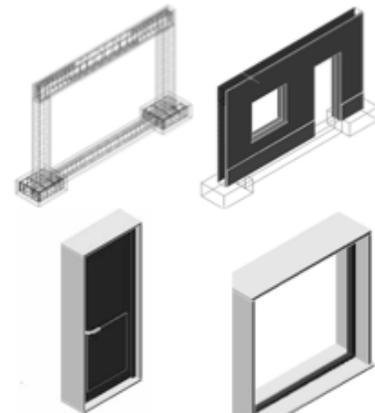


Fig. (1). 3D models of the masonry wall components.

- The type of masonry selected corresponds to an external wall formed by a **double panel of breezeblocks**, 11 cm, wide with an air cavity, 6 cm, wide (Fig. 1).
- Finally, two usual bay elements, a **door** and a **window**, were modeled (Fig. 2).

One by one every part of each element considered as a building component of the wall was modeled. Figure 2 shows the complete 3D model of the wall.

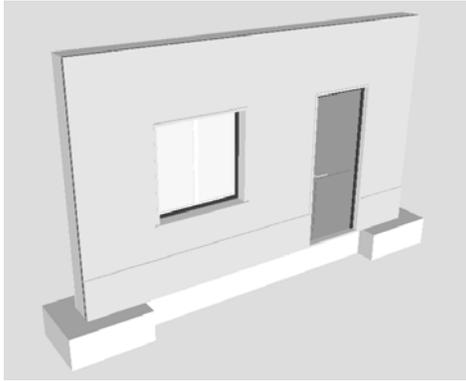


Fig. (2). The complete 3D model of the wall.

### PROGRAMMING THE VIRTUAL CONSTRUCTION

Next, the 3D model was exported as a *3DStudio-drawing* file (with the file extension *.3ds*) to the VR software, *EON Studio*. In this system, the visual simulation of the building process of the wall, following a realistic plan of the construction progress, was programmed. For this effect, 23 phases of construction were considered. The order in which components are consecutively exhibited and incorporated into the virtual model, represent realistically the physical evolution of the wall under construction (Fig. 3):

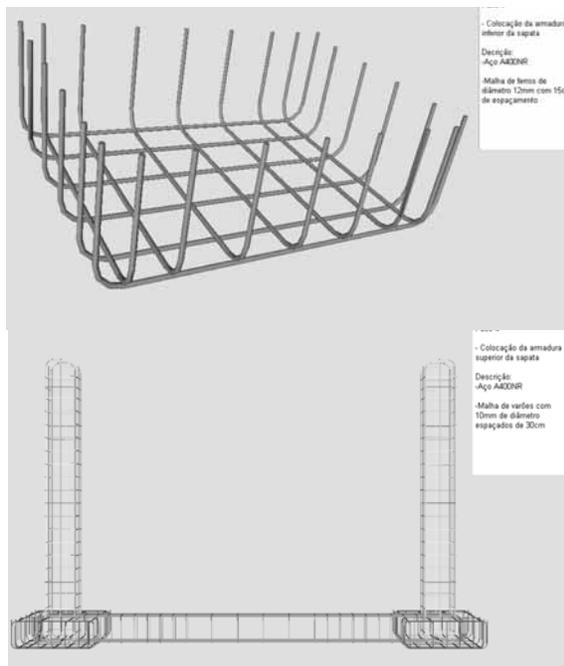


Fig. (3). Exhibition of two initial phases in building evolution.

- 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;
- It is possible to **highlight** the component incorporated at each new phase and to observe it in detail (Fig. 4);
- 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 filled, progressively, with small rectangles symbolizing the percentage built at the time of the viewing of that particular phase, in relation to the completed wall construction (Fig. 4). Symbolically, it represents the bar diagrams normally used on construction plans;
- Simultaneously, with the visualization of each phase, a **text** is shown (in the upper right corner of the window, Fig. 5), giving data relating to the stage being shown, namely, its position within the construction sequence, the description of the activity and the characterization of the material of the component being incorporated.
- Finally, the animation allows the user to visualize some components of the wall in an **exploded exhibition**. Figure 6 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.

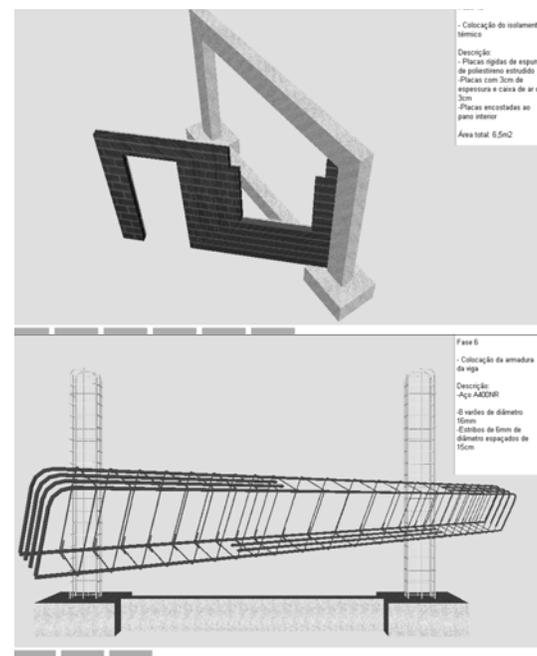


Fig. (4). Elements displaced from the global model of the wall.

The development of the model was supported by engineer specialist in construction activity. So this is a guarantee that the model shows the construction **sequence in a correct way** and the **configuration** of each component was **defined with accuracy**. In this educational application, it was important to include didactic and technical details such as: bar showing the construction progress; text with information

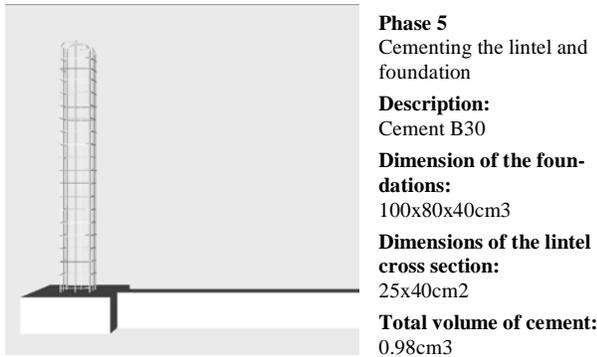


Fig. (5). Presentation of text describing the exhibited phase.

concerning the stage observed; the possibility to highlight elements from the model; the accuracy of the reinforcements and the way they connect in the joint zone of the structural elements; the details of the configuration of vertical panels and components of the window and the door.

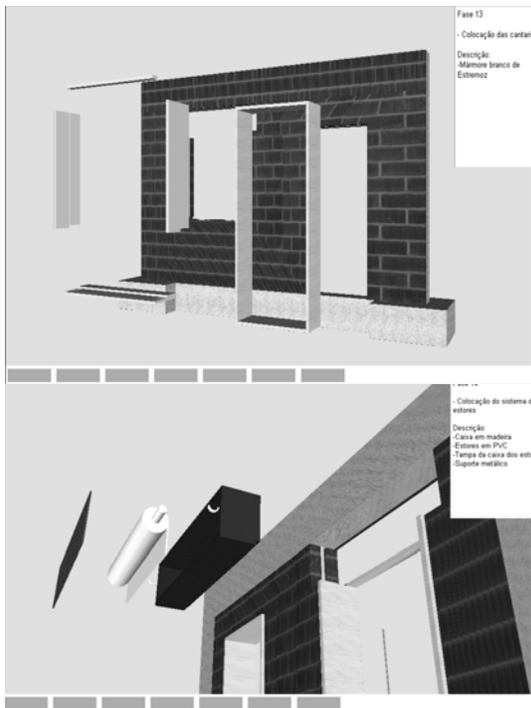


Fig. (6). Pictures presenting components visualized in explosion.

**3D MODEL OF THE BRIDGE**

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 ordering 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 standard plan of this type of work.

The North Viaduct of the Bridge Farm, in Madeira, Portugal, was the case selected for representation (GRID 1995)

[11]. In cross-section, the deck of the viaduct shows a box girder solution and its height varies in a parabolic way along its three spans (Fig. 7).

The most common construction technique for this typology is the cantilever method of a deck construction. This method starts by concreting a first segment over each pillar, the segment being long enough to install on it the work equipment. The construction of the deck proceeds with the symmetrical execution of the segments starting from each pillar.

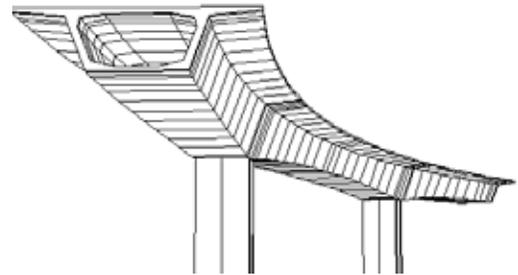


Fig. (7). 3D model of the bridge.

The continuation of the deck, linking the cantilever spans, is completed with the concreting of the closing segment. The support of specialist in bridge designs was essential to obtain an accurate model, not only on the geometry definition of the bridge components and devices, but also on the establishment of the progression sequence and of the way the equipment operates.

**GEOMETRIC MODELING OF THE CONSTRUCTION ENVIRONMENT**

A computer graphic system which enables the geometric modeling of a box girder bridge was used to generate 3D models of deck segments, necessary for the visual simulation of the construction of the bridge. Figure 8 shows the interface to describe the cross-section of the deck.

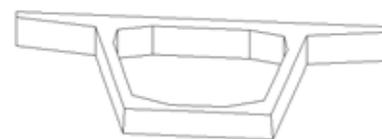
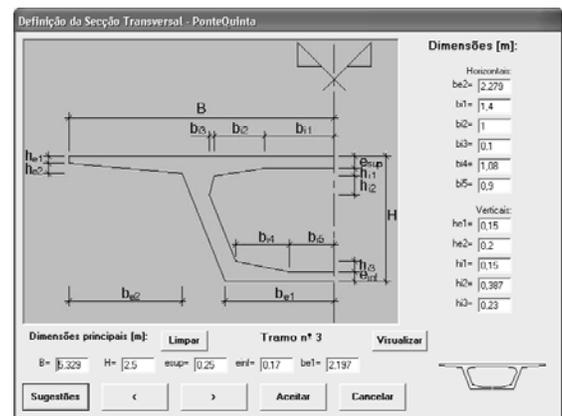


Fig. (8). Interface to describe cross-section and the 3D model of a deck segment.

The description of the longitudinal variation of the deck section height and the geometry of the layout the road was carried out using similar interfaces. The configuration and the spatial positioning of cross sections generated along the deck are obtained with a high degree of accuracy. Figure 8 shows one of the **segments** of the deck modeled automatically by the bridge system.

Using the *AutoCAD* system the **pillars** and **abutments** were also modeled. Then followed the modeling of the **advanced equipment**, which is composed not only of the form traveler, 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. 9).

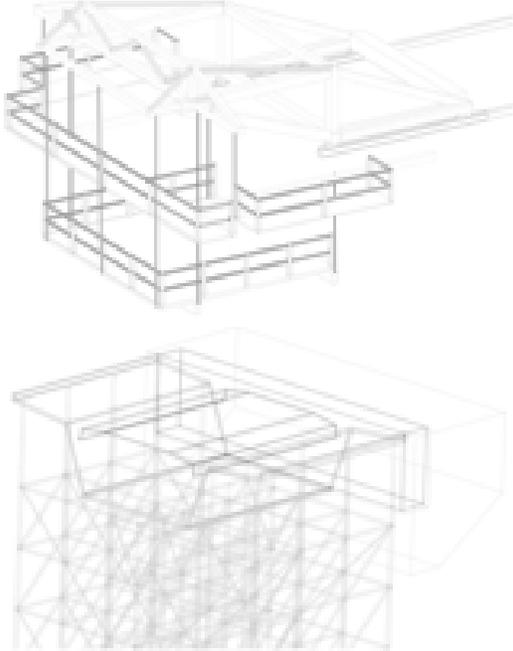


Fig. (9). 3D models of the scaffolding and the advanced equipment.

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 modeled (Fig. 9). **Terrain** suitable for the simulation of the positioning of the bridge on its foundations was also modeled.

### PROGRAMMING THE VIRTUAL ENVIRONMENT

The association of virtual capacities over the geometric model of the bridge was implemented using the virtual reality system *EON Studio*. The animation of the construction sequence is based on a counter, which determines the next action when a mouse button is clicked (Fig. 10):

- The first action consists of the insertion of the pillars in the initial scenario, composed solely of the landscape;
- The next step is to place one of the segments on the top of each pillar. After this, a form traveler is placed on each segment;
- The construction of the deck is defined symmetrically in relation to each pillar and simultaneously.

For the simulation of the first cantilever segment (in each span), the four form travelers, the corresponding work platforms and the formwork components are included in the sce-

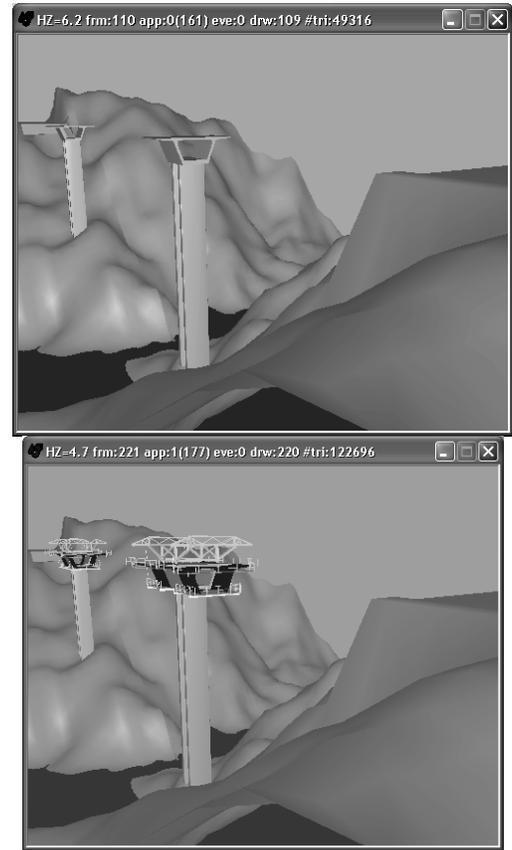


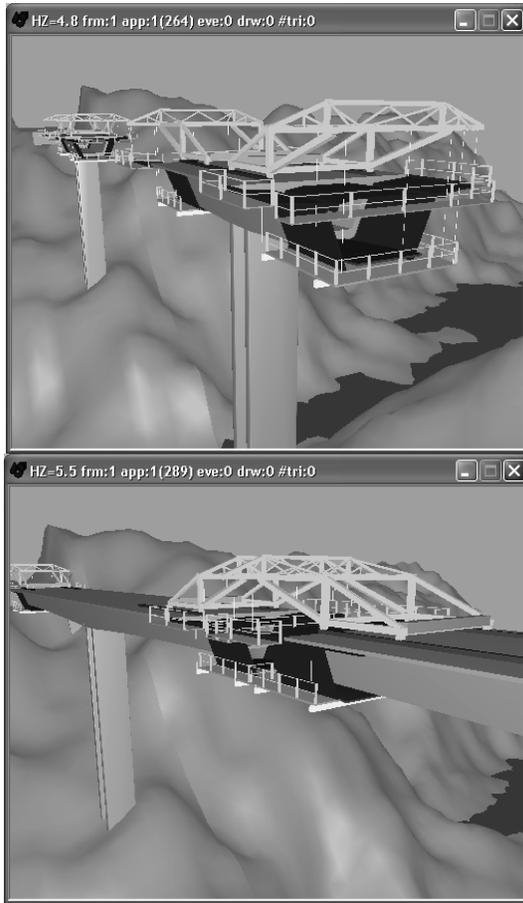
Fig. (10). Placing the initial pillars and the advanced equipment.

nario. Once the first segments have been concreted, the construction of the cantilevered deck takes place. In each phase, two pairs of segments are defined. For each new segment the following steps are established (Fig. 11):

- Raising the form traveler;
- Moving the rails in the same direction as the construction (relocating them on the latest segment that have been concreted);
- Moving the form traveler on the rails, positioning it in the zone of the next segment to be made and then concrete the segment (Fig. 11).
- Finally, using just one car the closing segment is defined and the zone of the deck near the supports is constructed over the false work resting on the ground (Fig. 12).

Moving the camera closer to the model of the bridge and applying to it routes around the zone of interest, it is possible to visualize the details of the form of the components involved in the construction process. In this way, the student can interact with the virtual model, following the sequence specifications and observing the configuration details of the elements involved.

In a real work place of a construction bridge, for security reasons, the student must remain far from the local were bridge is under construction, so they can not observe in detail the way of operation and the progression of the construction. Interacting with the model of the bridge in class or using their personal computers they better understand what is going on at the construction place.

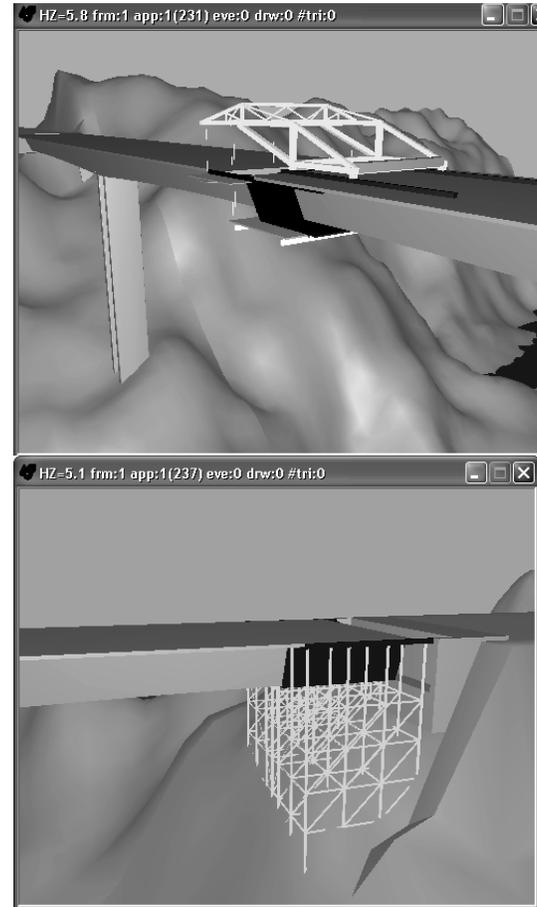


**Fig. (11).** Movement of the advanced equipment.

## LEARNING ASPECTS

The models are actually used in face-to-face classes of disciplines of Civil Engineering curriculum: Technical Drawing (1<sup>st</sup> year), Construction Process (4<sup>th</sup> year) and Bridges (5<sup>th</sup> year). 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 sequence construction and the constitution of the modeled type of work. Essentially, the models are used to introduce new subjects.

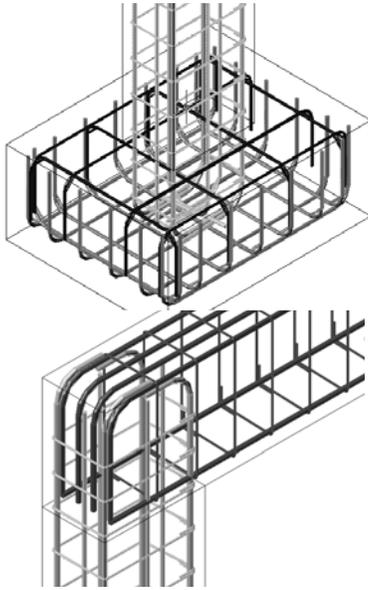
- As in **Technical Drawing**, students have to outline structural plants over the architectural layouts, the virtual model of the wall helps to explain the connection between the architectural drawings and the structural solutions needed to support the building shape. Some indication must be assumed when choosing a structural solution in order to minimize the unpleasant visual appearance in the interior of a house when structural elements (beams, columns, ...) are included in it. The students are 1<sup>st</sup> year degree, so they have some difficulty to understand the spatial localization of the structural elements and how they must be built and located almost inside the walls. The relationships between the architectural configurations and the structural elements in a building are well explained following the exhibition of the virtual construction of the wall. Is significant the degree of perception that the students actually demonstrate



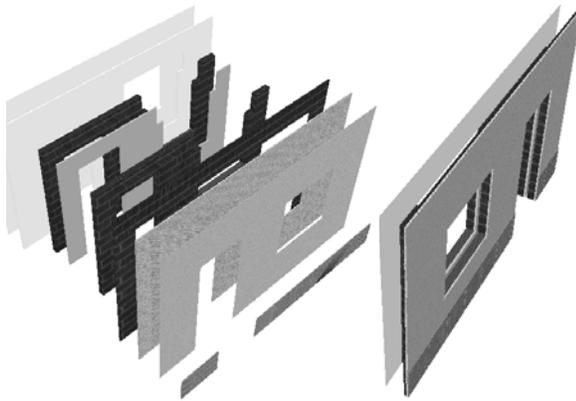
**Fig. (12).** Construction of the closing segment and concreting above the false work near the abutment.

on the drawings they carry out in classis when comparing to the performance of the students of previous years, without the visualization of the virtual wall model.

- In the discipline of **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 of a building. Namely, the way the net of irons is defined inside a beam or a column and specially the complexity of the relationship between the distinct types of irons near the zone where the structural elements connect each other (Fig. 13). In order to explain this issue related to the structural elements, the iron nets were created as 3D models with distinct colors, and they are introduced on the virtual scenario following a specific planned schedule. The model clearly shows the relative position of all iron nets inside the structural elements.
- 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. Figure 14 includes the vertical panels presented in explosion: two brick panels; the thermal isolation plate placed between the brick panels; the plaster applied to the external surface of the wall; the stucco applied on the internal surface; two coats of



**Fig. (13).** Complex relationship between reinforcements in the join zones of the structural elements.



**Fig. (14).** Vertical panels of the wall presented in explosion.

paint both inside and out and the stone slabs placed on the exterior surface.

- It also shows the configuration detail of the elements of the door and the window, completing the wall model (Fig. 6). The lecturer or the student themselves can manipulate the virtual scenario of the construction. So, when they go to visit real work places the reports they must write are now more objective and contextualized from those written by the students of the earlier years.
- The construction model of a **bridge** particularly shows the complexity associated to the execution of a box girder deck of a bridge. The model shows the construction of the deck that is done in a symmetric way and also allows the observation of the movement of the advanced equipment needed in the work. In the classroom, the professor must explain way the process must follow that sequence of steps and the way the equipment devices operates. When the student, of the 5<sup>th</sup> year, goes to the work place he can observe the complexity and the sequence of construction previously explained. Especially for these students it's important the interaction

with the virtual scenarios so often that they need to have a good perception of the movement of the advanced equipment associated to the constructive process shown in the model.

The students can also interact with those models. For that, the models were included on the Internet pages of Civil Engineering courses. The students are able to interact with the application *EonX*, accessed at: <http://download.eonreality.com>.

## CONCLUSIONS

It has been demonstrated, through the presented examples, how the technology of virtual reality can be used in the elaboration of teaching material of educational interest in the area of Construction Processes. The pedagogical aspects and the technical concepts are attended on the elaboration of both models.

The applications generated represent two standard situations of constructions. The student can interact with the virtual model 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.

These models are used in disciplines involving construction in Civil Engineering and Architecture courses. They can be used in classroom-based education and in distance learning supported by e-learning technology.

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