

VIRTUAL REALITY TECHNOLOGY APPLIED IN ENGINEERING EDUCATION

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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. But, the visual simulation of the construction process of a building need models which are able to produce dynamic changes to their geometry. This paper reports how techniques of geometric modelling and virtual reality 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 work, concerning the construction of a cavity wall and a bridge, 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 and to support the study of the type and method of operation of the equipment necessary in the construction process. These models have been used to distinct advantage as educational aids in first-degree courses in Civil Engineering. 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.

KEYWORDS: education, engineering, simulation, 4d models, virtual reality.

1 INTRODUCTION

Normally, three-dimensional (3D) geometric models, which are used to present architectural and engineering work, show only the final form, not allowing the visual simulation of their physical evolution. Models which deal with construction need to be able to produce changes to the geometry of the project. The integration of geometrical representations of a building with scheduling data related to construction planning information is the basis of 4D (3D + time) models (Liston, K. et al, 2001). In the field of construction 4D models integrate 3D models and the project timeline. In addition Virtual Reality (VR) technology has been used to make 4D models more realistic allowing interaction with the environment showing the construction site. Lately VTT Building Technology has been developing and implementing applications based on this technique, facilitating better communication between partners in construction projects (Leinonen, J. et al, 2003). The use of 4D models only linked to construction planning software or to virtual/interactive capacities, brings essentially economic and administrative benefits through the visual simulation of the “real situation” of the work at several points in its evolution. Those models are created for each particular project and are most usually manipulated by the principal designer or contractor. In other cases they are used to explain complex or innovative construction processes to subcontractors. When modelling 3D environments a clear intention of what to show must be planned, because the objects to be displayed and the details of each one must be made appropriate for 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 corresponding physical situation according to the established construction diagram and with the appropriate degree of detail. Developing didactic models for students involves technical tasks, at a level that undergraduate students are able to understand but which can be exploited for teaching purposes, too.

In the present study, two engineering construction work models were created, from which it was possible to obtain three-dimensional models corresponding to different stages in their formation thus simulating distinct stages in the construction process (Sampaio, A. et al, 2004). In order to create models, which could visually simulate construction work and allow interaction with it, the authors turned to techniques of virtual reality. The developed applications make it possible to show the physical evolution of the work, the monitoring of the planned construction sequence, and the visualization of details of the form of every component of each construction. They also assist the study of the type and method of operation of the equipment necessary for these construction procedures. The aim of the practical application of virtual models is to provide support in civil engineering education, particularly in those disciplines relating to bridges and construction process, both in classroom-based education and in distance learning based on e-learning technology. Specialists in construction processes and bridge design were consulted and involved in constructing the models in order to obtain efficient and accurate didactic applications. The selected examples are two elementary situations of construction work:

- An external wall, a basic component of a building;

- And the cantilever method of bridge decks construction which is frequently used.

In the construction of virtual models some pedagogical considerations and technical knowledge were taken into account as demonstrated in the selection of the quantity and type of elements to be shown in each virtual model, in decisions concerning the sequence in which they are to be shown, in the relationship established between the components of both types of construction, in the degree of geometric detail needed to be presented and in the technical information that must accompany each stage of construction. Further details positively complement educational applications rendering them more useful and efficient. In particular, the model of the wall shows information concerning construction activity of interest to students. This corresponds to the geometric stage displayed at each moment. The bridge construction model focuses on the movement of the equipment in operation during the progression. This means that when students go on site visits, since the essential details have previously been presented and explained in class, they are better able to understand the construction operation they are observing.

In addition, the use of techniques of virtual reality in the development of these didactic applications brings benefits to education by improving the efficiency of the models in the way they allow interactivity with the virtual activity. The virtual model can be manipulated interactively allowing the teacher or student to monitor the physical evolution of the work and the construction activities inherent in its progression. 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.

2 VIRTUAL 3D MODEL OF THE WALL

One of the developed applications is that of the model of a masonry cavity wall, one of the basic components of a standard construction. To enable the visual simulation of the construction of the wall, the geometric model generated is composed of a set of elements, each representing one component of the construction. The selection of elements and the degree of detail of the 3D model configuration of each component were made in consultation with teachers and construction specialists. Using the *EON Reality system* (EON, 2003), a system of virtual reality technologies, specific properties were applied to the 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 had been used to distinct advantage as an educational aid in Civil Engineering degree course modules.

2.1 Geometric modelling of the construction elements

The definition of the 3D model of an exterior wall of a conventional building comprises the structural elements (foundations, columns and beams), the vertical filler panels and two bay elements (door and window). Every element was modelled 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 each reinforcement are shown as tubular components with circular cross-section (Figure 1).

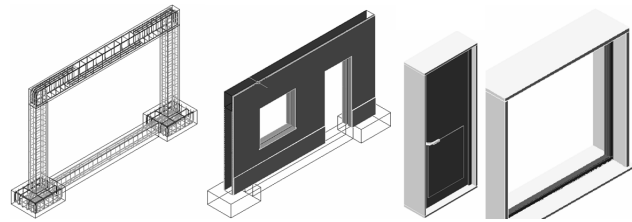


Figure 1. 3D models of the masonry wall components.

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 (Figure 1). Complementary to this, the vertical panels were modelled, comprising: 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 paint both inside and out and the stone slabs placed on the exterior surface. Finally, two usual bay elements, a door and a window, were modelled.

2.2 Programming the virtual construction

The completed model was then transferred to the virtual reality system *EON* (as a design file with *3ds* extension). 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 the physical evolution of the wall under construction (Figure 2):

- 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 examine it in detail;
- 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. Symbolically, it represents the bar diagrams normally used on construction plans.

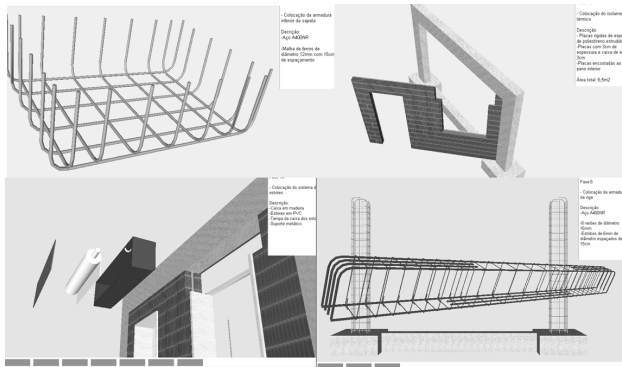


Figure 2. Exhibition of phases in building evolution.

Simultaneously, with the visualization of each phase, a text is shown (in the upper right corner of the window, Figure 3), 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.

In order to guarantee the authenticity of the model as far as the construction sequence and the definition of each component was concerned, engineers specializing in construction activities were consulted. In this educational application, it is important to include details such as: a bar showing the progress of the construction; text with information concerning the stage shown; the possibility of highlighting elements from the model; the accuracy of the grid of reinforcements and the way they connect inside the structural elements; the details of the configuration of vertical panels and components of the window and the door. On the occasions when a 4D model is used on a specific programme where some of these details are not essential, then they are not modelled in such detail.

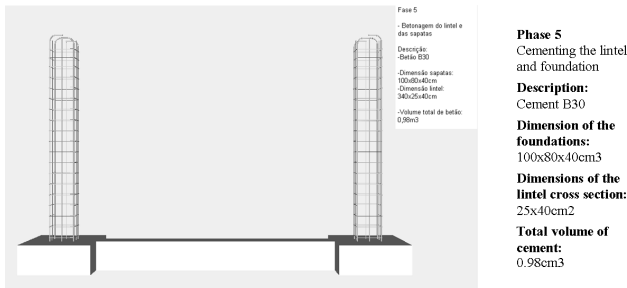


Figure 3. Presentation of text describing the exhibited phase.

3 VIRTUAL 3D MODEL OF THE BRIDGE DECK

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

The North Viaduct of the Bridge Farm, in Madeira, Portugal, was the case selected for representation in the virtual environment (GRID, 1995). In cross-section, the deck of the viaduct shows a box girder solution and its height

varies in a parabolic way along the length the three spans of the structure. The most common construction technique for this typology is the cantilever method of deck construction. This method starts by applying concrete to a first segment on 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. The continuation of the deck, uniting the cantilever spans, is completed with the positioning of the closing segment. Again the support of an appropriate specialist this time in bridge designs was essential in order to obtain an accurate model, not only of the geometry definition of components of the bridge and devices, but also of the establishment of the progression sequence and of the way the equipment operates.

3.1 Geometric modelling of the construction scenario

A computer graphic system which enables the geometric modelling of a bridge deck of box girder typology was used to generate 3D models of deck segments necessary for the visual simulation of the construction of the bridge (Sampaio, A., 2003). Geometric description can be entered directly into the deck-modelling program. To achieve this, the developed interface presents diagrams linked to parameters of the dimensions, so facilitating the description of the geometry established for each concrete case of the deck. Figure 4 shows the interface corresponding to the cross-section of the deck in the example.

The description of the longitudinal morphology of the deck and the geometry of the delineation of the service road, serving the zone where the bridge is to be built is carried out in the same way. The configuration and the spatial positioning of each are obtained with a high degree of accuracy. Using the data relating to the generated sections, the system creates drawings and three-dimensional models of the deck. To obtain the definition of the deck segment models, consecutive sections corresponding to the construction joints are used. The configuration presented by each segment model is rigorously exact. Figure 4 shows one of the segments of the deck.

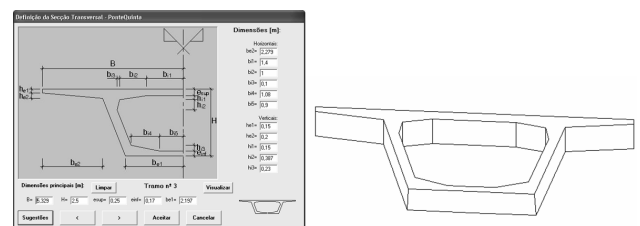


Figure 4. Interface of to describe cross-section s and the 3D model of a deck segment.

To complete the model of the bridge, the pillars and abutments were modelled using the *AutoCAD* system. Then followed the modelling of the advanced equipment, which is composed not only of the form traveller, but also the formwork adaptable to the size of each segment, the work platforms for each formwork and the rails along which the carriages run (Figure 5). As, along with the abutments, the deck is work out with the false work on the ground, the scaffolding for placement at each end of the deck was also modelled (Figure 5). Terrain suitable

for the simulation of the positioning of the bridge on its foundations was also modelled.

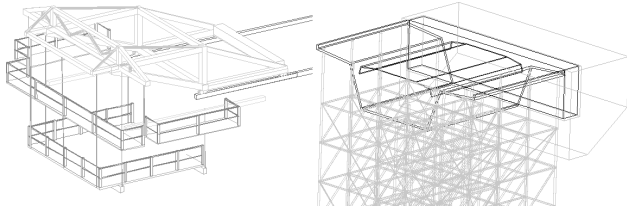


Figure 5. 3D models of the scaffolding and advanced equipment.

3.2 Programming the construction sequence

The attribution of virtual properties to the model of the bridge was implemented by using the virtual reality system *EON Studio*. Once all the 3D models of the construction environment had been generated, they were transposed, in *3ds* extension data file format, to the virtual reality system. The definition of the construction sequence is based on a counter, which determines the next action when a mouse button is clicked. The first action consists of the insertion of the pillars in the first scenario, which is 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 traveller is placed on each segment. The construction of the deck is defined symmetrically in relation to each pillar and simultaneously in both directions.

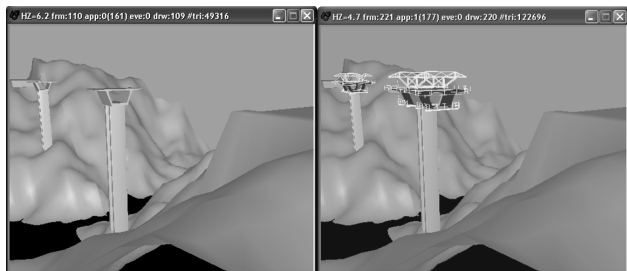


Figure 6. Placing the initial pillars and the advanced equipment.

For the simulation of the first cantilever segment (in each span), the four form travellers, the corresponding work platforms and the formwork components are included in the scenario. Once the first segments have been dealt with, 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:

- Raising the form traveller;
- Moving the rails in the same direction as the construction (relocating them on the latest segment to have been completed);
- Moving the form traveller on the rails, positioning it in the zone of the next segment to be made; completing the segment;
- Finally, the zone of the deck near the supports is constructed, the false work resting on the ground (Figure 7).

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 details of

the configurations of the elements involved. This interaction with the virtual model is greatly beneficial to students. When the students are visiting an actual construction site, they have to stay at a distance for safety reasons, so are unable to observe the operation and progress of the building in any detail. Having interacted with the model of the bridge in class or on their personal computers they are better able to understand what is happening in the real construction zone.

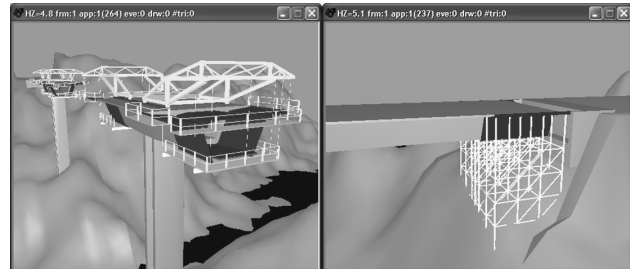


Figure 7. Movement of the advanced equipment and concreting above the false work near the abutment.

4 LEARNING ASPECTS

The models are actually used in face-to-face classes of certain subjects in the Civil Engineering curriculum: Technical Drawing (1st year), Construction Process (4th year) and Bridges (5th year). Traditionally, the curricular subject matters included in the virtual models, have been presented through 2D layouts or pictures. Now, the teacher interacts with the 3D models showing the construction sequence and the constitution of the type of work modelled. Essentially, then, the models are used to introduce new subjects:

- As in Technical Drawing, students have to define and draw structural plans 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 house configuration. During the presentation of the model, students should learn those technical elements relating to the selection of structural solutions in particular those that minimize the impact of the inclusion of elements (such as beams and columns) in the house interiors on the aesthetics. Students in the first year of their degree course usually have some difficulty in understanding the spatial localization of the structural elements and how they must be built and located almost inside the walls. However, once they have seen the virtual construction of the wall, the relationships between the architectural configurations and the structural elements in a building are well understood.
- When the Construction Process is being taught, in order to prepare these first year students to visit real work places, the teacher shows the animation of the construction and explains some aspects of the construction process of the wall, in particular, the way the iron grid is defined inside a beam or a column and especially the complexity of the connection between the different types of grids of iron reinforcements near the zone where the structural elements connect to each other (Figure 8). In order to clearly explain this issue

related to the structural elements, the iron grids were created as 3D models with distinct colours, and they appear on the virtual scenario following a specific schedule. 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 of them. The configuration detail of each element of a complete wall can be clearly observed by manipulating the virtual scenario of the construction.

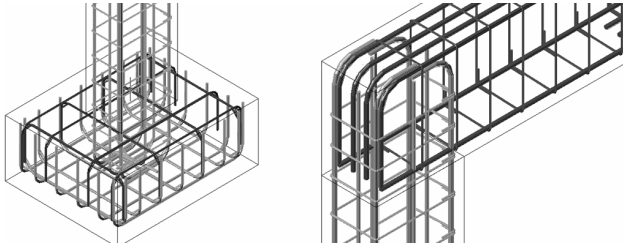


Figure 8. Complex relationship between reinforcements in the joint zones of the structural elements.

- The construction model of a bridge particularly shows the complexity associated with the concrete work of the bridge deck that is carried out symmetrically. The model also shows, in detail, the movement of the advanced equipment. In class, in this case in the fifth year, the lecturer must explain why the process must follow that sequence of steps and the way the equipment functions. When the student goes to the work place he can observe the complexity and the sequence of construction previously explained.

It is also an advantage for students to be able to interact with these models. For this reason, the models were posted on the Internet pages of undergraduate courses in Civil Engineering, where they can interact with the application *EonX* (EON Viewer, 2006).

5 CONCLUSIONS

It has been demonstrated, through the examples presented here, how the technology of virtual reality can be used in the producing teaching material of educational interest in the area of construction processes. The pedagogical aspects and the technical concepts inherent in the curricular subject material presented were taken into consideration during the construction of the model.

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 construction elements mesh with each other and become incorporated into the model.

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

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