SIMULATION OF CONSTRUCTION PROCESSES WITHIN VIRTUAL ENVIRONMENTS

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Keywords: Didactic models, Education, Virtual reality, Visual simulation.

Abstract: Three-dimensional geometric models have been used to present architectural and engineering works, showing their final configuration. But, when the clarification of a detail or the constitution of a construction step in needed, these models are not appropriate because they do not allow the observation of the construction activity. Models that could present dynamically changes of the building geometry are a good support on education in civil engineering domain. Techniques of geometric modelling and virtual reality were used to obtain interactive models that could visually simulate the construction activity. The applications explain the construction work of a cavity wall and a bridge. The models present 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 civil construction.

1 INTRODUCTION

Normally, three-dimensional (3D) geometric models, which are used to present architectural and engineering works, show only their final form, not allowing the visual simulation of their physical increasing. The models concerning construction needs to be able to produce changes of the geometry of the project. 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). In construction field 4D models combine 3D models with the project timeline (Retik, 1997). In addition Virtual Reality (VR) technology has been used to turn 4D models more realistic allowing interaction with the environment representing the construction place. 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).

The use of 4D models just linked with construction planning software or with virtual/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 step of its evolution. Those models are created for each particular project and are mostly manipulated by the principal designer or contractor.

Developing didactic models for students concerns technical tasks, at a level that could be understood by undergraduate students, but also pedagogical judgments. 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 their shape, simulating distinct stages in construction processes (Sampaio, 2006). In order to create models, which could visually simulate the construction work and allowing interact with it, techniques of virtual reality were used. 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 methodologies (Sampaio and Henriques, 2004).

2 DIDACTIC VIRTUAL MODELS

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. Specialist in construction processes and bridge design were consulted and involved in the execution 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, on the sequence of exhibition to follow, on the relationship established between the components of both type of construction, on the degree of geometric details needed to present and on the 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. Namely, the model of the wall shows the information concerning construction activity of interest for students corresponding to the geometric stage displayed in each moment and the bridge construction model shows particularly the movement of the equipment in operation during the progression.

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 interactively allowing the teacher or student to monitor the physical evolution of the work and the construction activities inherent in its progression. 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 and 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.

3 3D MODEL OF THE WALL

One of the developed applications corresponds to 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 had the support of teachers and specialist in construction. 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.

3.1 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 the reinforcements are shown as tubular components with circular cross-section (Figure 1).
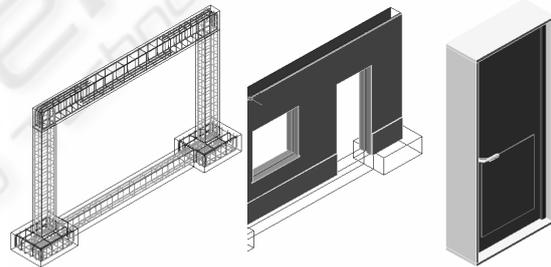
Figure 1: 3D models of the wall components.

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.

3.2 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 realistically the physical evolution of the wall under construction (Figure 2).
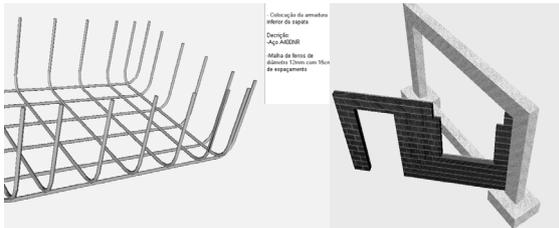
Figure 2: Exhibition of phases in building evolution.

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 examine it in detail (Figure 3).

Figure 3: Elements displaced from the global model of the wall.

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 (Figure 3). 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, Figure 4), 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.

Phase 5
Cementing the lintel and foundation
Description:
Cement B30
Dimension of the foundations:
100x80x40cm3
Dimensions of the lintel cross section:
25x40cm2
Total volume of cement:
0.98cm3
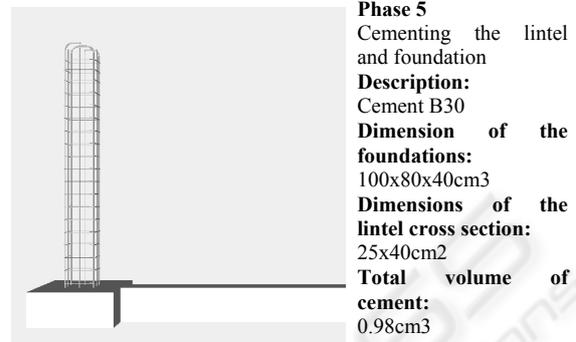
Figure 4: Presentation of text describing the exhibited phase.

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 is important to include details such as: bar showing the construction progress; text with information concerning the stage observed; the possibility to highlight elements from the model; the accuracy of the reinforcements and the way then connect inside the structural elements; the details of the configuration of vertical panels and components of the window and the door.

4 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 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, 1997). 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. 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. The support of specialist in bridge designs was essential to obtain an accurate model, not only on the geometry definition of components of the bridge and devices, but also on the establishment of the progression sequence and of the way the equipment operates.

4.1 Geometric Modelling of the Construction Environment

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. 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 5 shows the interface corresponding to the cross-section of the deck of 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 the segment models is rigorously exact. Figure 5 shows one of the segments of the deck.

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 6).
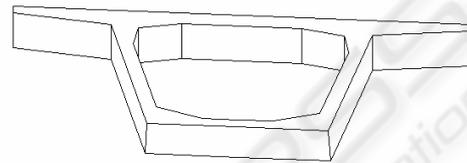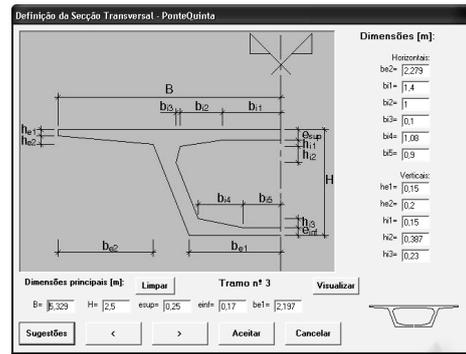
Figure 5: Interface to describe cross-sections and the 3D model of a deck segment.
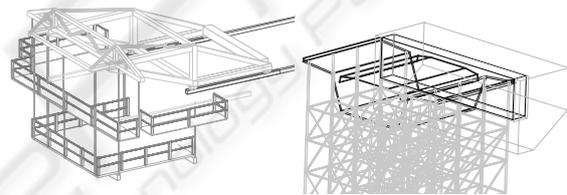
Figure 6: 3D models of the scaffolding and the advanced equipment.

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 modelled (Figure 6). Terrain suitable for the simulation of the positioning of the bridge on its foundations was also modelled.

4.2 Programming the Construction Animation

The attribution of virtual properties to the model of the bridge was implemented by using the virtual reality system *EON Studio* (EON, 2003). 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 (Figure 7).

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 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: aising the form traveller; moving the rails in the same direction as the construction (relocating them on the latest segment to have been concreted); moving the form traveller on the rails, positioning it in the zone of the next segment to be made; concrete the segment. Finally, the zone of the deck near the supports is constructed, the false work resting on the ground (Figure 8).
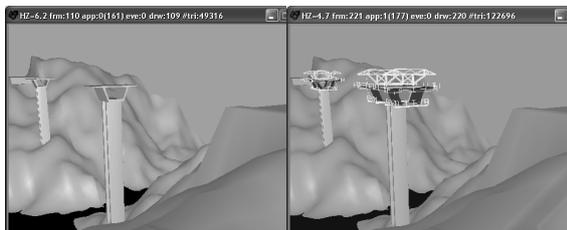
Figure 7: Placing the initial pillars and the advanced equipment.

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.
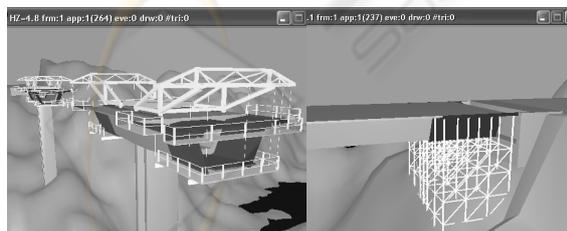
Figure 8: Movement of the advanced equipment and concreting above the false work near the abutment.

In a real construction place of a bridge, for security reasons, the student stays far from the local were bridge is under construction, so they can't 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 there in the construction zone.

5   LEARNING ASPECTS

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

As in Technical Drawing, students have to define and draw 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 house configuration. 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 1st 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.

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 the wall. 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 (Figure 9).

In order to clearly explain this issue related to the structural elements, the iron nets were created as 3D models with distinct colours, and they appear on the virtual scenario following a specific planned 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 other. The configuration detail of each element of a complete

wall can be clearly observed manipulating the virtual scenario of the construction.
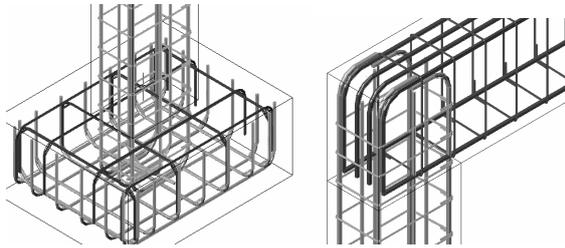
Figure 9: Complex relationship between reinforcements in the join zones of the structural elements.

The construction model of a bridge particularly shows the complexity associated to the concrete work of the deck bridge that is done in a symmetric way. The model also shows in detail the movement of the advanced equipment. In class, 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 5th year, goes to the work place he can observe the complexity and the sequence of construction previously explained.

The students can also interact with those models. For that, the models were posted on the Internet pages of undergraduate courses in Civil Engineering. The student will be able to interact with the application *EonX,* which can be accessed at: http://download.eonreality.com.

6 CONCLUSIONS

It has been demonstrated, through the examples presented here, 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 courses in Civil Engineering and Architecture. They can be used in classroom-based education and in distance learning supported by e-learning technology.

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