

# Virtual Reality Models used on the Visualization of Construction Activities in Civil Engineering Education

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**Abstract**—Three-dimensional geometric models have been used to present architectural and engineering works, showing their final configuration. When the clarification of a detail or the constitution of a construction step is needed, these models are not appropriate. They do not allow the observation of the construction progress of a building. Models that could present dynamically changes of the building geometry are a good support to the elaboration of projects. Techniques of geometric modeling and virtual reality were used to obtain models that could visually simulate the construction activity. The applications explain the construction work of a cavity wall and a bridge. These models allow the visualization of the physical progression of the work following a planned construction sequence, the observation of details of the form of every component of the works and support the study of the type and method of operation of the equipment applied in the construction. These models presented 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.

**Keywords**—Education, Engineering, virtual reality, visual simulation.

## I. INTRODUCTION

NORMALLY, three-dimensional (3D) geometric models, which are used to present architectural and engineering works, show only their final configuration, not allowing the observation of their construction process. The visual simulation of the construction process needs to be able to produce dynamic changes to the geometry of the project. It is then important to extend the usefulness of design information to the construction planning. The integration of geometrical representations of buildings together with scheduling data is the basis of 4D (3D + time) models in construction domain. 4D models combine 3D models with the project timeline [1]. 4D-CAD models are being used frequently to visualize the transformation of space over time. To date, these models are

mostly purely visual models. On a construction project, a 4D-CAD environment enabled the team, involved in the project, to visualize the relationships between time (construction activities) and space (3D model of the project) [2]. Virtual reality (VR) allows the interactive real-time viewing of 3D building models and can greatly facilitate the process of visualizing, evaluating and communicating new building designs.

In order to create models, which could visually simulate the construction process of two types of construction work, the authors turned to techniques of geometric modelling and virtual reality. The applications developed for this purpose refer to the construction of a *masonry cavity wall* and a *bridge*. These models 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 virtual model can be manipulated interactively allowing the student/teacher to monitor the physical evolution of the work and the construction activities.

One of the applications shows the construction of a masonry cavity wall, a basic component of a standard building. 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. Using a system of virtual reality technologies, specific properties concerning the virtual environment are applied to the model. 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 is used in disciplines concerning the construction process and the concepts related to relationships between the architecture and the structure aspects in a building. The 3D model, incremented step by step, shows in a clear way the type of connection between each component in a traditional construction and how the structural elements must be related with the architecture configuration.

The second model created allows the visual simulation of

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the construction of a bridge using the cantilever method. The geometric model of the bridge deck was created through a bridge modelling system, developed by Sampaio [3]. The same system of virtual reality was used to program the visual simulation of the bridge construction activities. 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 what is usually planned in this type of work. The aim of the practical application of the virtual model of bridge construction is to provide support in those disciplines relating to bridges and construction process.

These models have been used to distinct advantage as an educational aid in Civil Engineering degree course modules, both in classroom-based education and in distance learning based on e-learning technology.

## II. VIRTUAL MODEL OF THE CONSTRUCTION OF AN EXTERNAL WALL

An exterior wall of a standard building was modeled and the virtual properties were applied in order to create an interactive model that allows the visual simulation of its construction [4]. The model of the masonry cavity wall, including the structure of the surrounding reinforced concrete and the bay elements, was created using *AutoCAD*. The virtual environment was applied to the model through the *EON Studio* system [5].

### A. Geometric modelling of the elements of the wall

The representation of the 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 (a door and a window).

The structural elements of the model were created with parallelepipeds and were connected according to their usual placement in building works. The steel reinforcements were defined as extruded elements with circular cross-section (Fig. 1).

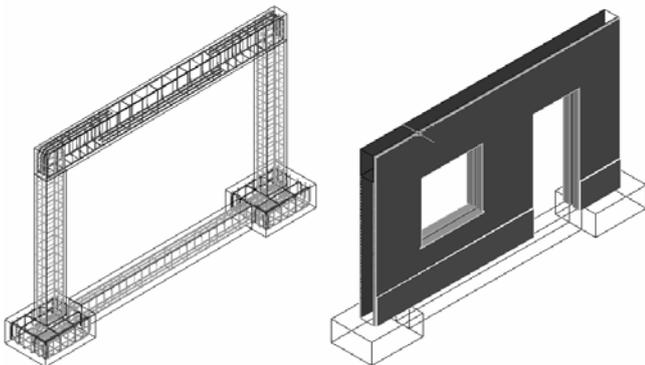


Fig. 1 3D models of the structural and vertical panels of the wall.

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. Several vertical panels were modelled: thermal isolation plate placed between the brick

panels; plaster applied to the external surface of the wall; stucco applied on the internal surface; two coats of paint both inside and out; stone slabs placed on the exterior surface (Fig. 2). Finally, a door and a window were modelled (Fig. 3).

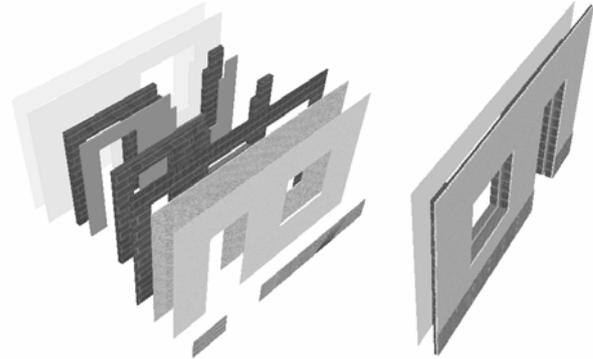


Fig. 2 Vertical panels of the wall presented in explosion.

One by one every part of each element considered as a building component of the wall was modeled. Fig. 3 shows the complete 3D model of the wall. 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 particular plan, was programmed.

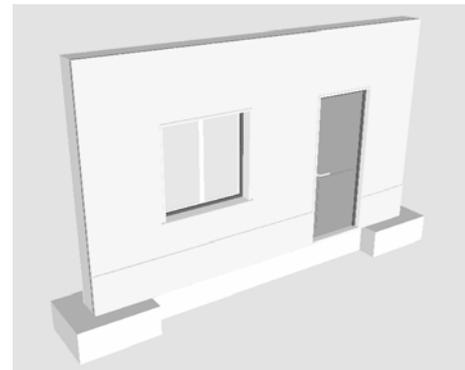


Fig. 3 The complete 3D model of the wall.

### B. Definition of the virtual environment of the construction process

The construction process was decomposed in 23 phases following the real execution of this kind of element in the work place. The programmed animation simulates the progression of the wall construction. For each construction step the correspondent geometric model is shown. In this way, the virtual model simulates the changes that really occur while the wall is in construction in a real work place. The first element to become visible, in the screen, is the steel reinforcement of the foundation (Fig. 4) and the last is the door pull.

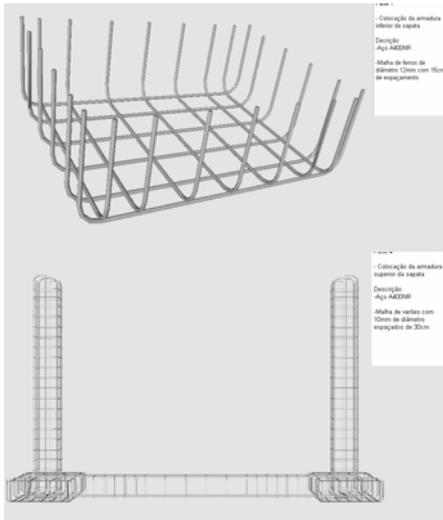


Fig. 4 Presentations of two steps of the virtual construction progress.

Manipulating the camera with zooms and several orientations over the model, all configuration details that the components of a real wall must present can be observed and understood by the student. For each new wall component becoming visible in a construction phase, the virtual model allows the user to pick the element and to manipulate the camera around it (Fig. 5). The student can then observe the element, displaced from the global model of the wall, from any point of view.

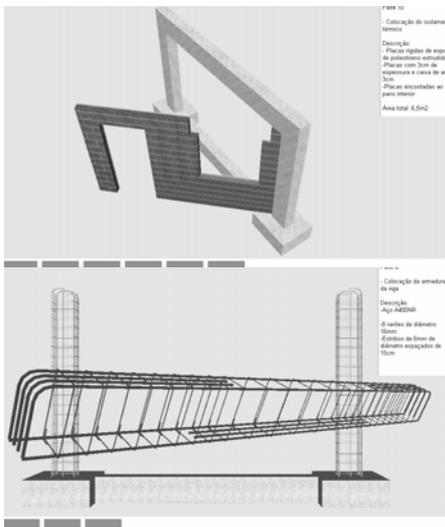


Fig. 5 Pictures presenting elements displaced from the global model of the wall.

Included, under the visualization area, 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. 5).

While the animation is in progress, a box text is presented, fixed at the upper right corner of the display (Fig. 6). It contains construction information about the step in

exhibition.

The text includes the number, the activity description and the material specification and quantification concerned to each phase. The visualization of this type of data following the virtual construction evolution is useful to students.

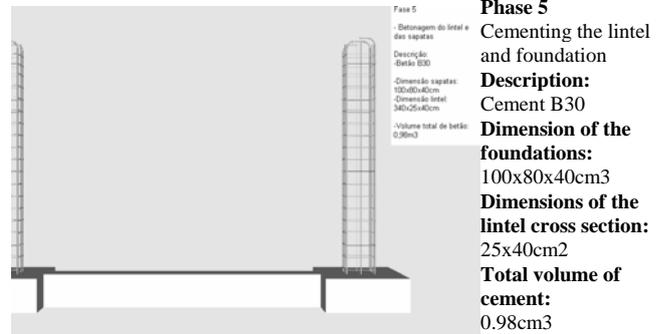


Fig. 6 Presentation of text describing the exhibited construction step

Finally, the animation allows the user to visualize some components of the wall in an exploded exhibition. Fig. 7 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.

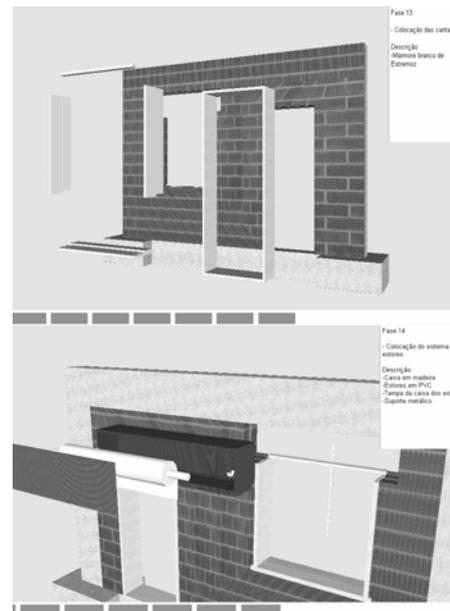


Fig. 7 Pictures presenting components visualized in explosion.

Along 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.

The development of the model was supported by engineer specialists in construction domain. 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.

### III. VIRTUAL MODEL OF THE BRIDGE CONSTRUCTION

The second virtual model shows the construction of the bridge. A geometric modeling system of bridge deck of the type box girder was used to generate 3D models of the deck segments [3]. The attribution of virtual properties to the model was implemented using the same virtual reality system.

The North Viaduct of the Bridge Farm in Madeira, Portugal, was the case selected [6]. In cross-section, the deck of the viaduct shows a box girder solution and its height varies in 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 positioning of the segments starting from each pillar.

In order to be able to manipulate the construction work of the bridge in virtual environment, in addition to the 3D models of each segment, models of the pillars, form travellers, abutments and false work were created. The spans were defined using the bridges graphical system and the remaining components through *AutoCAD*. All the components of the construction virtual place were transposed to the *EON system*, proceeding, then, to the definition of the desired animation.

#### A. Modelling the elements of the construction environment

Geometric description can be entered directly into the deck-modeling 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. Fig. 8 shows the interface corresponding to the cross-section of the deck. 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 3D models of deck segments.

To complete the model of the bridge, the pillars and abutments were modelled. The advanced equipment was also modelled, composed with: form traveller; formwork adaptable to the size of each segment; work platforms for each formwork; rails along which the carriages run (Fig. 9). As, near 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 (Fig. 9).

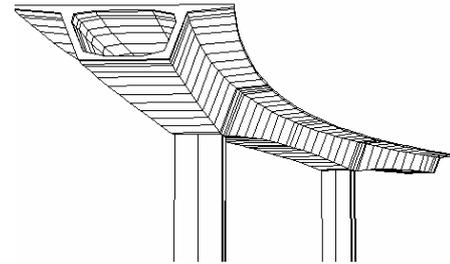
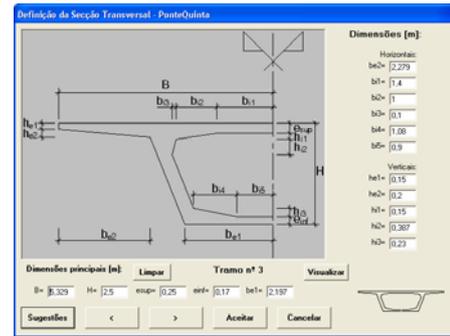


Fig. 8 Description of cross-sections of the deck and the 3D model of the bridge.

Terrain suitable for the simulation of the positioning of the bridge on its foundations was defined as well.

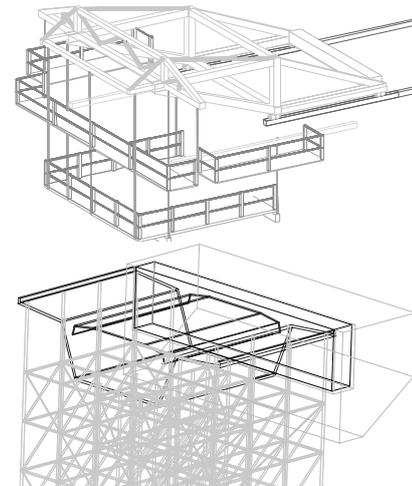


Fig. 9 3D models of the abutments, false work, scaffolding and advanced equipment.

#### B. Programming the animation of the virtual construction

Once all the 3D models of the construction environment had been generated, they were transposed to the virtual reality system. The animation of the construction process was programmed following an accurate plane for the visual simulation of the work progression (Fig. 10):

- 1) The first action consists of the insertion of the pillars in the first scenario, which is composed solely of the landscape;
- 2) The next step is to place an initial segment over the top of each pillar;
- 3) After this, a form traveller is placed on each segment;

- 4) 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;

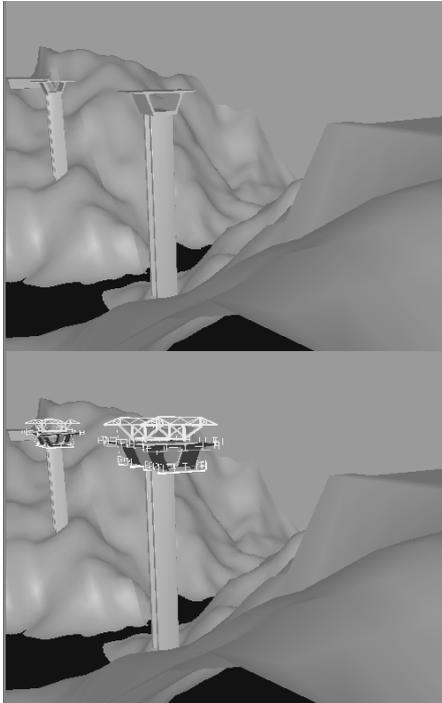


Fig. 10 Placing the initial pillars and segments and the advanced equipment.

- 5) The construction of the deck is defined symmetrically in relation to each pillar and simultaneously. 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 concreted); moving the form traveller on the rails, positioning it in the zone of the next segment to be made; concrete the segment;
- 6) The continuation of the deck, uniting the cantilever spans, is completed with the positioning of the closing segment and finally, the zone of the deck near the abutment is constructed, using a false work resting on the ground (Fig. 11).

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.

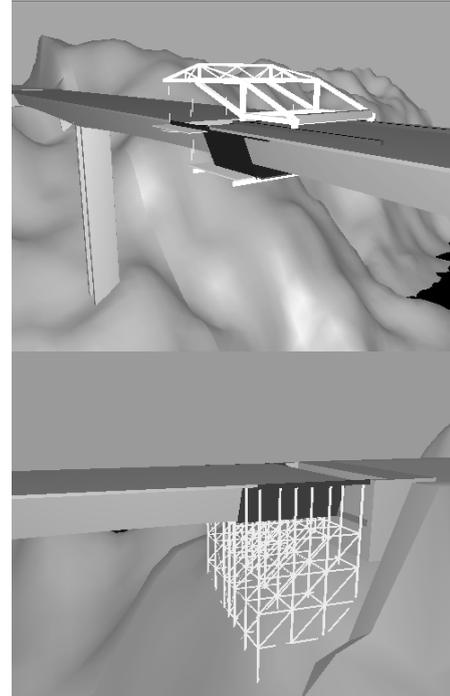


Fig. 11 Construction of the closing segment and the work near the abutment.

#### IV. 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 composition of the modelled building element. Essentially, the models are used to introduce new issues.

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 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 relationship between the architectural configuration and the structural components in a building are well explained following the virtual exhibition of the wall's construction.

In the discipline of *Construction Process*, in order to prepare students to visit local 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

complex relationship between the distinct types of steel reinforcements in the zone where the structural elements connect each other. In order to clearly explain this issue related to the structural elements, the iron nets were created as 3D models with distinct colors, and they become visible on the virtual model 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 relative position between each other.

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 the way of displacement of the advanced equipment. In class, the teacher must explain way the process must follow that sequence of steps and the movement of the equipment devices. When a 5<sup>th</sup> degree student 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 included on the internet pages of undergraduate Civil Engineering course.

## V. 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 models generated represent building in two standard situations. 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, analyse 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 administered by the Department of Civil Engineering of the University of Lisbon. They can be used in classroom-based education and in distance learning supported by e-learning technology.

## REFERENCES

- [1] J. Leinonen, K. Kähkönen, and A. Retik, "New construction management practice based on the virtual reality technology", in *4D CAD and Visualization in Construction: Developments and Applications*, R. A. Raja, Ed., A. A. Balkema Publishers, 1993, pp. 75-100.
- [2] K. Liston, M. Fischer, and T. Winograd, "Focused sharing of information for multi-disciplinary decision making by project teams", *International Journal ITcon*, vol. 6, pp. 69-82, 2001.
- [3] A. Sampaio, and A. Recuero, "A geometric modeling of box girder deck for integrated bridge design", *International Journal of Computer Applications in Technology, IJCAT, Special issue on Interoperability for SME- based environments*, 20(1), pp. 54-61, 2004.
- [4] A. Sampaio, P. Henriques, and P.S. Ferreira, "A virtual environment tool applied to visualize construction processes", in *Proc. TP.CG.04 – Theory and Practice of Computer Graphics 2004 Conference*, Bournemouth (U.K.), 2004, pp. 78-85.

- [5] "Introduction to working in EON Studio", EON Reality, Inc. 2003.
- [6] "Graphical documentation of the design of North Viaduct of the Quinta Bridge, 1st phase", GRID Planning office, Lisbon, 1995.

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