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Review

Didactic models in engineering education supported on virtual reality technology

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Techniques of virtual reality (VR) were applied on the development of models related to the construction activity within Civil Engineering education context. The interaction allowed by 3D geometric models could make an end to passive attitudes of learners as an opposition to traditional teaching systems. In addition, VR technology could be applied as a complement to three-dimensional (3D) modeling, leading to a better communication between the various stakeholders in the process, whether in training, in education or in professional practice. The implemented models, showing construction processes of walls of buildings and bridges, allow the visualization of the physical progression of the work following a planned construction sequence, observation of details of the form of every component of the works and carrying the study of the type and method of operation of the equipment applied in the construction. Another didactic model supports student to draw up plan drawings of roofs and the correspondent 3D model, tasks which relies on an understanding of the three-dimensional nature of the respective constructive process. In the rehabilitation of buildings, 3D models helps the outcome of the building anomalies, to better understand the geometry of the environment where the rehabilitation is going to take place, to quantify the amount of work needed and to evaluate different alternative of rehabilitation. The main objective of the practical application of the models is to support class-based learning and they are adequate to be used in distance training based on e-learning platform technology. The involvement of VR techniques in the development of educational applications brings new perspectives to Engineering education.

Key words: Virtual reality, construction, Engineering Education, 3D models.

INTRODUCTION

At present times, the educational process includes many information and communication technologies based methods for teaching and learning. In addition, the use of graphical technologies in education is quite evident nowadays, namely in teacher training. Concerning the educational task, the interaction allowed by three-dimensional (3D) geometric models could make an end to passive attitudes of learners as an opposition to traditional teaching systems. In addition, virtual reality (VR) technology could be applied as a complement to 3D modelling, leading to a better communication between the various stakeholders in the process, whether in training, in education or in professional practice. This task is particularly relevant to the presentation of processes which are defined through sequential stages as generally is the case in the learning of new curricular subjects, as well the construction processes. Besides the constant up-dating of training in the new graphic resources available to engineering and architecture professions, and in widespread and frequent use, the school should also adapt its teaching activities to the new tools of visual communication. In fact, several software engineering is used today in practical discipline, which requires that future engineers have the competencies and knowledge to develop economical and feasible solutions. Undergraduate students must be educated and trained to

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perform the roles required for software development in order to create effective solutions (Juárez-Ramírez et al., 2009).

A school of engineering can be reasonably expected to constantly update computational resources which are in frequent use in the professions, resources which must be introduced into the training of the student, leading to their adaptation for curricula in these disciplines. In technical drawing, the adaptation has been gradual accompanying the appearance of new graphics systems/products supporting plan drawing and modeling. At present, the subject Computer Assisted Drawing (Integrated Master in Civil Engineering, at the Technical University of Lisbon) is contemplating the introduction a module on teaching a graphic system supporting Engineering activities. Its introduction is complemented by basic notions of Computer Graphics.

Another objective in creating didactic applications based on VR technology is to show in which way new technologies afford fresh perspectives for the development of new tools in the training of construction processes. Visual interaction can do some changes in the way engineering education is performed, both in learning new materials and in terms of explaining construction activities (Sulbaran and Baker, 2000). Normally, very little visual information is presented in engineering schools: Students mainly listen to lectures and read material written (Felder et al., 1988). But, most of the students are visual learners, so the visual interactive model is an interesting didactic tool. In professional contexts, note the contribution in Architecture/Engineering, to support for conception (Petzold et al., 2007), presenting the plan (Khanzode et al., 2007) or following the progress of construction (Leinonen at al., 2003). The application of VR in training, both surgical (Perez, 2008) and laboratory (Bell and Fogler, 2004), are references for models used in professional education. The virtual models can be very useful both in face-to-face classes and in distance learning using e-learning technology. VR provides opportunities to deliver technical education in ways not possible through traditional methods, thereby broadening the range of tools available to modern educators, in order to reach more students and subjects (Bell and Fogler, 2004).

This text intends essentially to highlight the new possibilities that the use of 3D modelling and VR could bring to engineering education and after on the activity of the students as professionals. The involvement of these techniques in the development of educational applications brings new perspectives to Engineering education:

1. The 3D models created to support rehabilitation projects helps to outcome the building anomalies and to evaluate different alternative of rehabilitation solutions;
2. The main objective of the practical application of the didactic VR models concerning construction processes is to support class-based learning. The models presented the construction of a wall, a bridge decks using two different methods and a roof.

3D MODELS IN CONSTRUCTION

At present, in carrying out a project in engineering or architecture, the use of graphic systems and, in particular, those relating to 3D modelling, makes a very positive contribution to improve the transmission of rigorously correct technical information and, in general, to the understanding of spatial configurations (Gero, 2000). This means of expression surpasses a drawing, a picture or a diagram, making the understanding of the real form more intuitive (Sampaio and Henriques, 2008). These systems support the creation of models defined in three dimensions, providing a distinct type of plane projection, without being limited as to localization, viewpoint, orientation or distance from the observation point.

Normally, in the construction contexts, the 3D geometric models are used to present architectural projects, showing only their final shape. They not allow the visual simulation of their physical modification. The models concerning construction needs to be able to produce changes of the project 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 (Leinonen at al., 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 expected situation of the work in several step of its evolution (Fisher, 2000).

Therefore in the construction industry, the general use of 3D and 4D models is the visualization of the building design for demonstration purposes to the client, and not as a design support system. The majority of the industry's clients are inexperienced in building design and construction processes. 3D building models are produced to show the client how their building will look like if they decided to procure the proposed project.

Rehabilitation is a kind of construction work where the final result is even more important, and it must be evaluated in a very early stage, before any decision or construction work became definitive. Rehabilitation must promote the preservation of the historical value of ancient buildings and improve a sustainable urban development. In the rehabilitation of buildings, the systems Computer-Aided Design (CAD) could be useful to the outcome of the building anomalies analyses and also to workout alternative solutions.

Two recent works regarding Bologna master thesis were developed at the TU Lisbon based on CAD technology. The students had to learn 3D advanced modelling. In both works, 3D model was an important tool

Figure 1. Perspectives of the historic building 3D model and alternative solutions for the stairs.

in order to survey the anomalies in the structures and to support decisions based on the visual analyses of alternative solutions of rehabilitation (Sampaioet al., 2009):

1. One case concerns the study of an historic building that was submitted to a rehabilitation process that includes the detection of structural anomalies, the replacement of damaged resistant elements and the adaptation of the building to new services (Figure 1). This application clearly demonstrates that the 3D geometric model allowed a quicker understanding of the structural organization of the building and it was a useful tool for the surveying and mapping of its damages. It would also be very useful for presenting different retrofitting solutions to the owner of the building and for helping him choose one of them, as it has been proved in the stairs comparison.
2. Another model considers the installation of new sanitary equipment in an old building, which presents a significant degree of degradation. In this case, two alterative solutions were workout and modelled (Figure 2). By manipulating the models, the understanding of all sanitary elements in the room is quite clear, better than just analyzing plan drawings. In both solutions, the information, concerning the specification of sanitary elements, the quantity of pipe elements for cool and water supplies, the quantity and characterization of materials for covering interior surface of walls and to place over the floor was carried out. The 3D models assist to workout this kind of data and to clearly analyze the space in an aesthetic point of view. The geometric model also helps to identify incompatibilities, when we need to introduce, new elements within old structures with few space.

So, the 3D model application is a very important tool, to support rehabilitation decisions. In both case studies, the 3D models were created in order to better understand the geometry of the environment where the rehabilitation is going to take place, to quantify the amount of work needed and to evaluate different alternative of rehabilitation. These works are a contribution to the acceptance of the use of CAD, not only as a good “drawer”, but also as an important support on the analyses of rehabilitation works. Both are student works. Thus, teaching CAD in school is helpful to students in

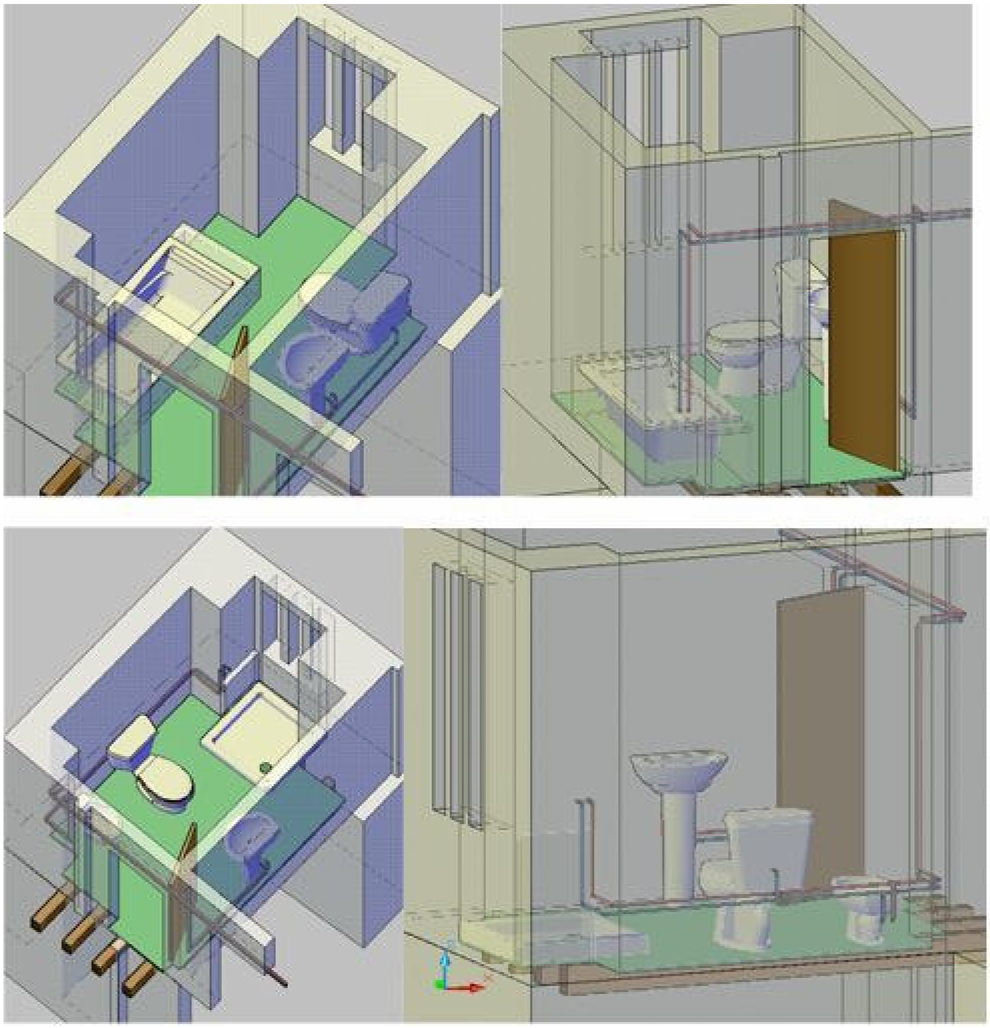


Figure 2. 3D models of two alterative solutions.

order to prepare them to consider this technology as an important support, later in professional activity, and also to facilitate the link between, engineering theory and its implementation. So, an architecture and engineering school can be expected to constantly update computational resources which are in frequent use in the professions. Resources should be introduced into the training of the student, leading to their adaptation for curricula in drawing and modelling disciplines (Duarte, 2007).

VR DIDACTIC MODELS

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 of the carrying out processes. In order to create models, which could visually simulate the progressive sequence of the process and allowing interaction with it, techniques of virtual reality were used. The aim of the practical application of the virtual models is to provide support in Civil Engineering education namely in those disciplines relating to drawing, bridges and construction process both in classroom-based education and in distance learning based on *e-learning* technology.

The developed applications make it possible to show the physical evolution of the works, the monitoring of the planned construction sequence, and the visualization of details of the form of every component of each construction. In construction, the selected examples are elementary situations of works:

1. One model presents the construction of an external wall, a basic component of a building (Sampaio and Henriques, 2008);
2. Another model attends the cantilever method of bridge deck construction, a method that is applied frequently (Sampaio et al., 2010);
3. Another model attends the incremental launching

method of bridge deck construction (Martins and Sampaio, 2009).
4. The roof model supports the explanation of subject matter pertaining to elevation projection representations applied to the design of roofs (Sampaio et al., 2009).

Specialist in construction processes and bridge design were consulted and involved in the execution of the construction models in order to obtain efficient and accurate didactic applications. They also assist the study of the type and method of operation of the equipment necessary for these construction methodologies. The pedagogic aspect and the technical knowledge transmitted by the models are present in 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. 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.

The use of techniques of VR 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 simulated environment of each 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 3D space, to repeat the sequence or task until the desired level of proficiency or skill has been achieved and to perform in a safe environment.

Model of the wall

The virtual model of a masonry cavity wall, one of the basic components of a standard construction, enables the visual simulation of its construction. For that 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. So 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).

Using the EON reality system (EON, 2008), 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 (Figure 3).

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 details such as:

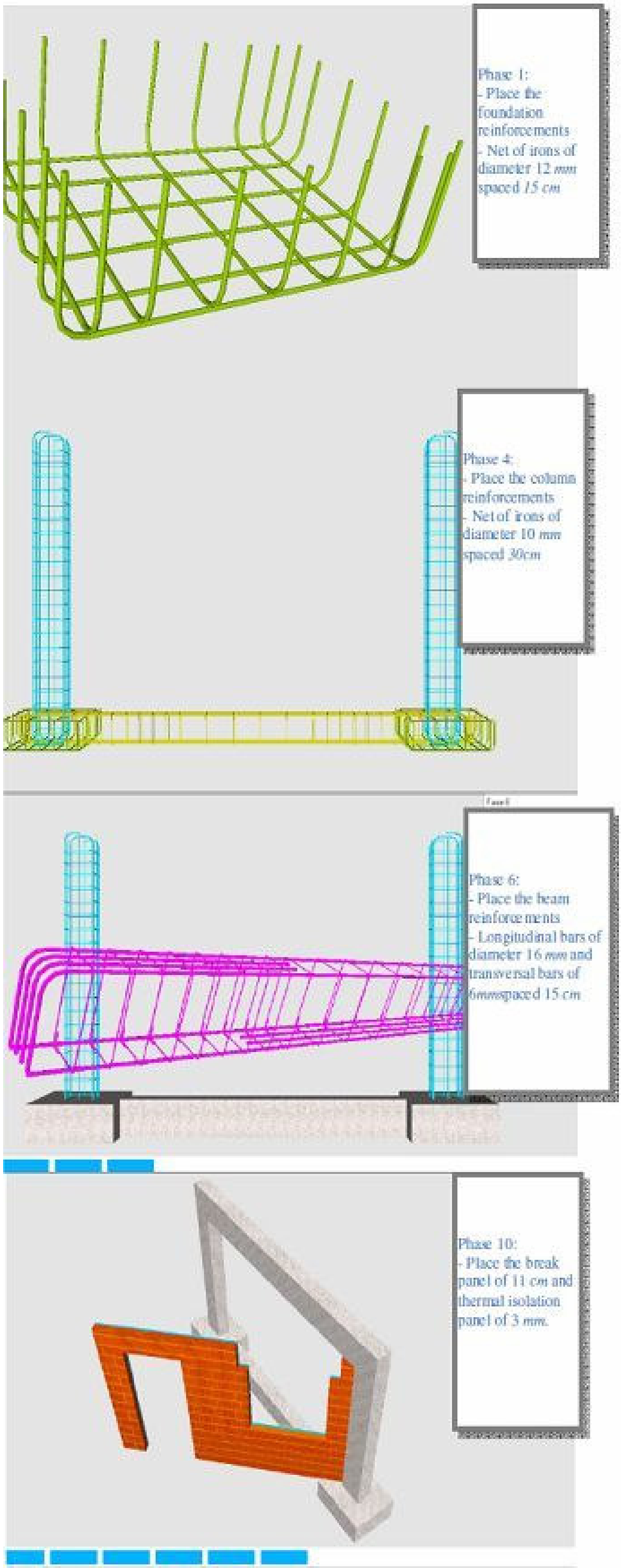
1. Bar showing the construction progress;
2. Text with information concerning the stage observed;
3. The possibility to highlight elements from the model;
4. The accuracy of the reinforcements and the way they connect inside the structural elements;
5. The details of the configuration of vertical panels and components of the window and the door.

The cantilever method of deck bridge construction

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 speed 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 study case created in a virtual environment. 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 bridge construction.

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, 2003). To complete the model of the bridge, the pillars and abutments were also modelled. 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 4). 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 4). Terrain suitable for the simulation of the positioning of the bridge on its foundations was also modelled.

The 3D model of the bridge and environment was transposed to the virtual reality system EON studio. The support of specialist in bridge designs was essential to



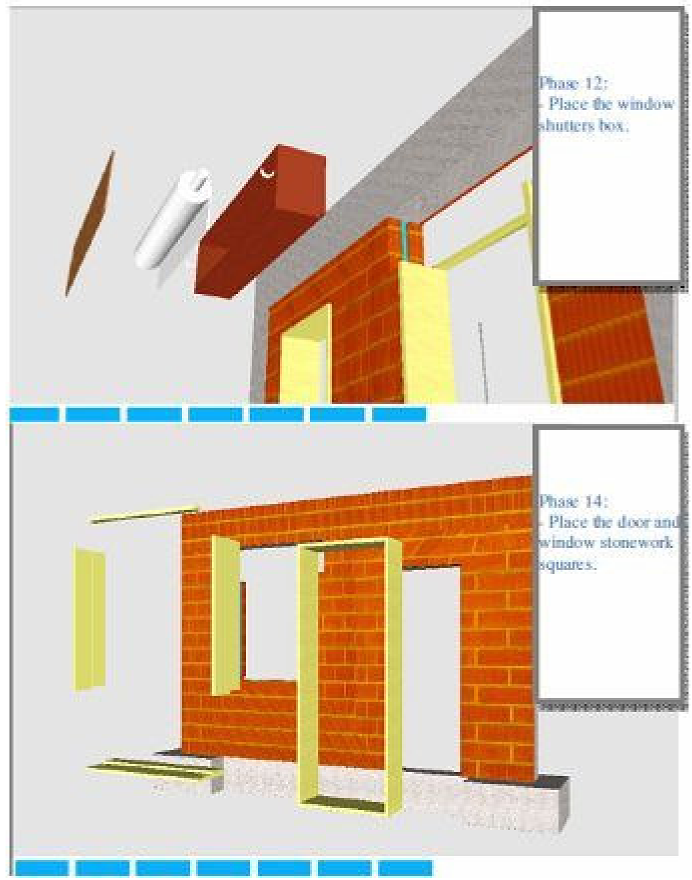


Figure 3. Exhibition of phases of the wall construction.

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 (Figure 5):

1. 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;
2. The construction of the deck proceeds with the symmetrical execution of the segments starting from each pillar, using the advanced equipment;
3. The continuation of the deck, joining the cantilever spans, is completed with the positioning of the closing segment;
4. The zone of the deck near the supports is constructed, using a false work resting on the ground.

Moving the camera closer to the bridge model and applying to it routes around the zone of interest, the student, interacting with the virtual model, can follow the sequence specifications and observing the details of the configurations of the elements involved (Figure 6).

In a real construction place of a bridge, for security

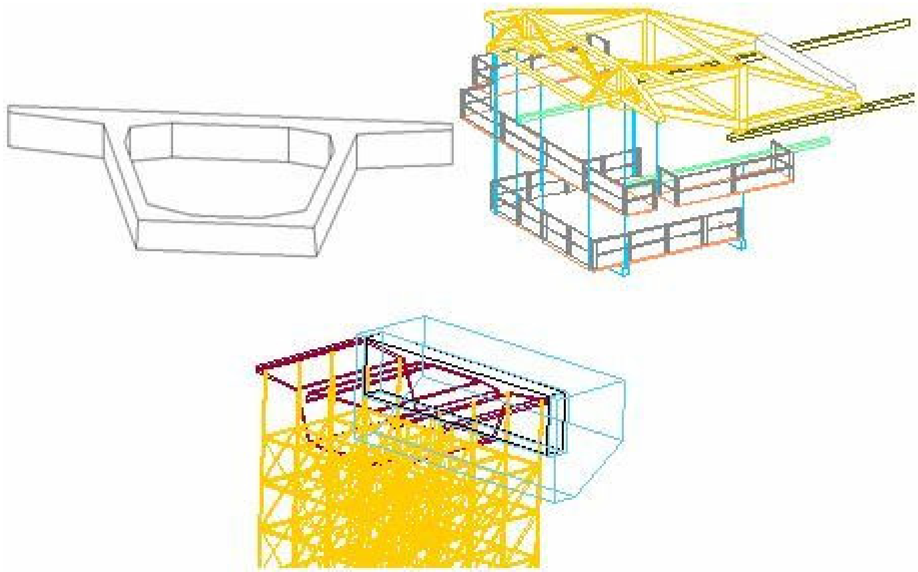


Figure 4. 3D models of a deck segment, the scaffolding and the advanced equipment.

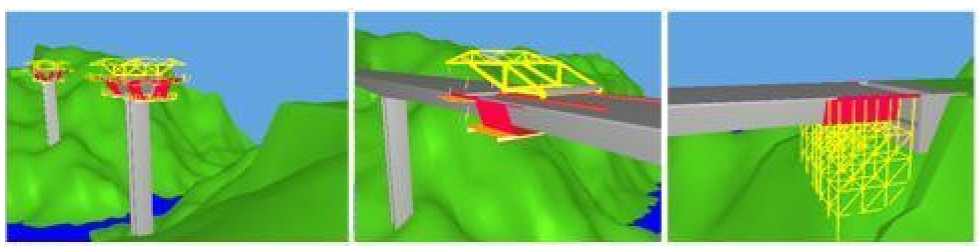


Figure 5. Movement of the advanced equipment and concreting near the abutment.

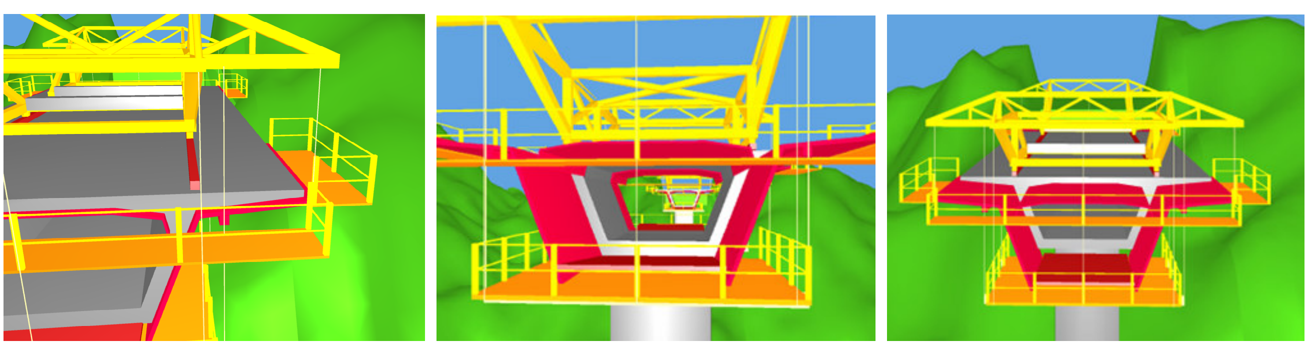


Figure 6. Movement the camera closer to the bridge model.

reasons, the student stays 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 in class or using their personal computers they understand better what is going on there in the work place.

The incremental launching method of deck bridge construction

Another interactive model concerning construction of deck bridges to support Civil Engineering education was created. The construction of bridge decks using the

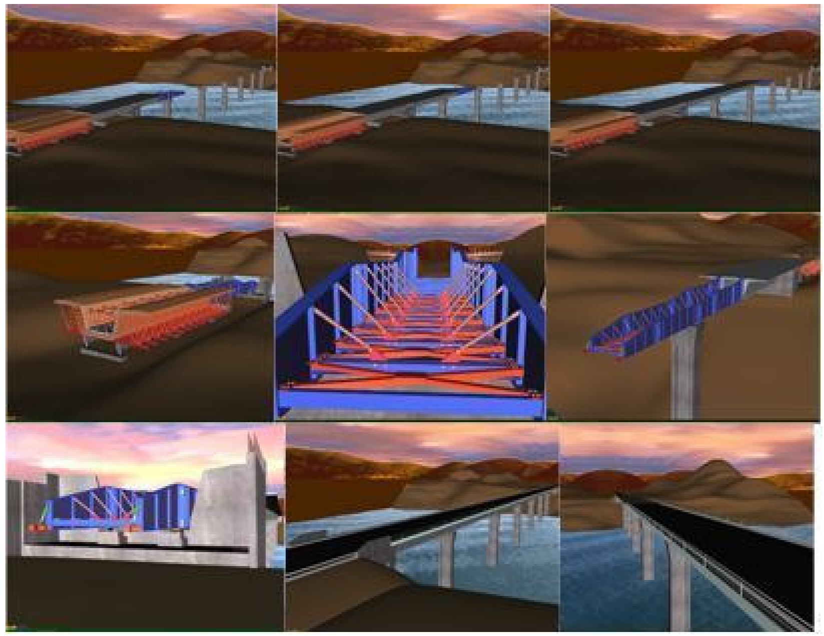


Figure 7. Sequence of the incremental launched of the deck.

method on incremental launching exist from the 60s. The incremental launching method consists of casting 15 to 30 *m* long segments of the bridge deck in a stationary formwork to push a completed segment forward with hydraulic jacks along the bridge axis. This method is appropriated in viaducts over valleys and mountains with spans about 50 *m*. The application of the process requires that the cross section of the deck is constant, because each section will have different states of bending moments and thus different tensions. The adequate type of section is the box girder.

The developed RV model provides a contribution to the dissemination of information concerning this construction method, through a recording of visual simulation of the phases and the equipment that comprises the construction process. Every elements needed in the virtual scenario were modelled and then the interaction was programmed using the some software based on the virtual reality technology, the EON studio. The 3D model of all elements was generated using AutoCAD.

During the animation, the position of the camera and its movement are synchronized to show the details of the elements or the assembly type and also an overview of the working place (Figure 7):

1. After placing the external panels of the shuttering and the reinforcement mesh, starts the visual simulation of the casting work;
2. The elements that make up the interior false work are placed incrementally, starting with the metallic support, followed by the longitudinal beams and finishing with the implementation of shuttering panels;
3. Next, the assembly of the launching nose is installed;
4. After casting the first segment, the displacement of this element takes place. For that, the temporary support of the nose is removed and the segment is separated from the shuttering.

The construction of the remaining segments is performed in fast mode, because the process is identical to the initial segment. Already in the final phase of construction, the yard is removed and the space is covered of land. Finally the guards are positioned and also other finishing elements.

The model was worked out attending both the technical knowledge and didactic aspects namely in how and what to show. It also attend that the model is going to be manipulated by undergraduate students of Civil Engineering. So, the model could be an important support to teachers to illustrate bridges construction issues in class and after, by themselves, using their PCs. The application is oriented, not only as a learning tool, but also to professionals related to the construction of this kind of bridges. The animation of the construction process can be visualized at http://www.octaviomartins.com/lancamentoIncremental/.

Model of the roof

Following from those examples, a proposal was put forward to generate an educational model related to the graphic construction of a roof drawing (Sampaio and Cruz, 2008). Representation using elevation projection is

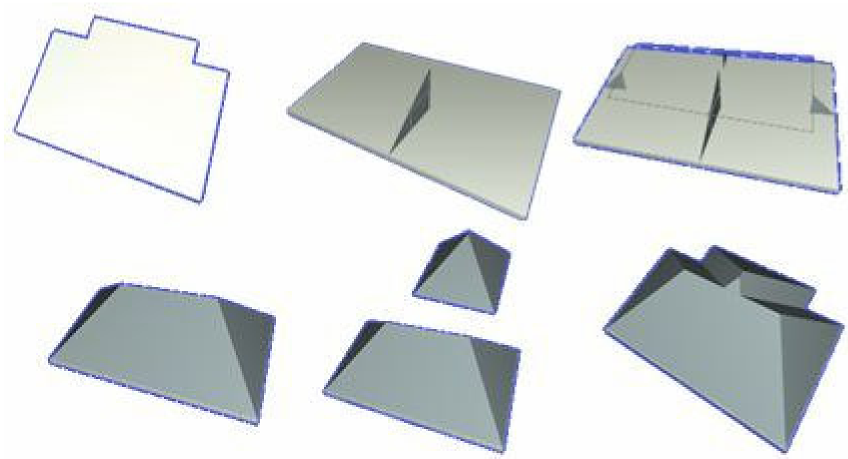


Figure 8. Animation sequence of the roof construction.

one of the topics in the subject of Technical Drawing included in the syllabus of the module on Computer Assisted Drawing. This representation uses only the view obtained by horizontal projection, the plan. However, the drawing is complemented by the relevant data, the elevations value and the graphics related to the three-dimensional space: The specification of the geometric outline of the roof and the slope of each of the roof planes of which it is made up. The animation of the model follows the sequence of operations illustrated in Figure 8:

1. Presentation of the initial base shape; subdivision of this shape into two polygons;
2. Placement of the triangle representing the slope value 2:3 next to one of the edges;
3. Insertion of the triangles with 1:1 pitch in normal positions for each of the edges;
4. Introduction of the polygon of the appropriate elevation; inclusion of the plane surfaces representing the 4 roof planes;
5. Representation of the second of the two blocks which make up the roof;
6. Intersection of the two roof blocks.

The VR model allows interaction with the modelling process sequence enabling the user to backtrack and manipulate the camera position and distance in relation to the model. The final objective of this model is to show the complete roof constructed on a basis of the concepts of engineering drawing applied to the plan drawing of that structure. The intersection of the two blocks of the roof clearly illustrates how roofs with more than four planes must be executed.

LEARNING ASPECTS

The VR models are actually used in face-to-face classes of disciplines of Civil Engineering curriculum: Computer Assisted Drawing and Technical Drawing (1st year), Construction Process (4th year) and Bridges (5th year). They were placed on the webpage for each discipline thus being available for students to manipulate, using the EON viewer application (EON, 2008). The traditional way to present the curricular subjects involved in these virtual models are 2D layouts or pictures. Now, the teacher can interacts with the 3D models showing the sequence construction and the constitution of the modelled type of work.

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 position 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 (Figure 9).

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, he describes the way the irons are organized inside beams or columns, specially the complexity of the relationship between reinforcements in the join zones of the structural elements. 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 appear on the virtual scenario following a specific planned schedule. 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

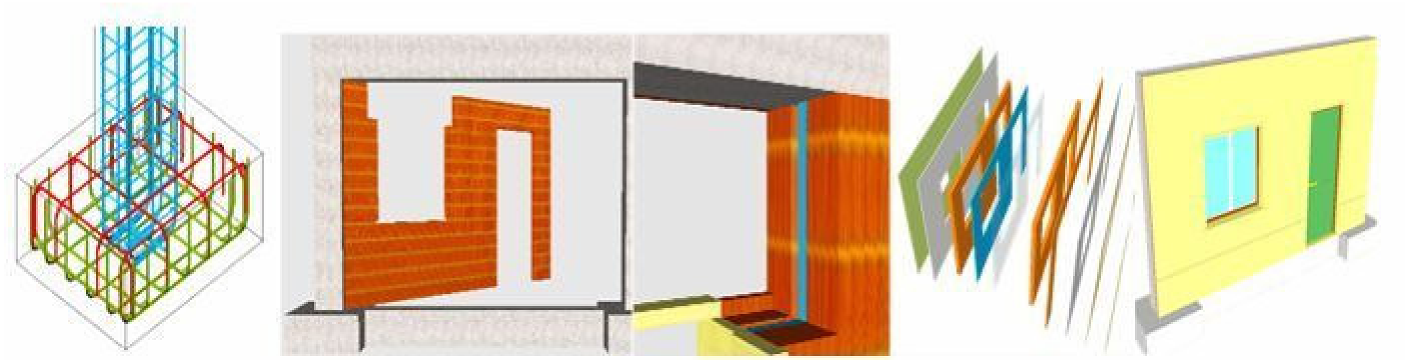


Figure 9. Reinforcements in the join zones and the relationships between the architectural configurations and the structural elements in a wall.

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;

The bridge models show the complexity associated to the construction work of the deck. Both models also illustrate in detail the movement of the equipment. In class, the teacher must explain the way the process must follow both sequence of steps and the way the equipment devices operates. When the student, of the 5^{th} year, goes to a real work place, he can observe the complexity of the work and better understand the progression of construction previously explained. Particularly, the incremental method model presents a great complexity of geometry and material concerning the different elements used in a real work process. It provides an immersive capacity inherent to virtual world and it has a menu of events display allowing the students and teachers to select a specific part (Figure 10).

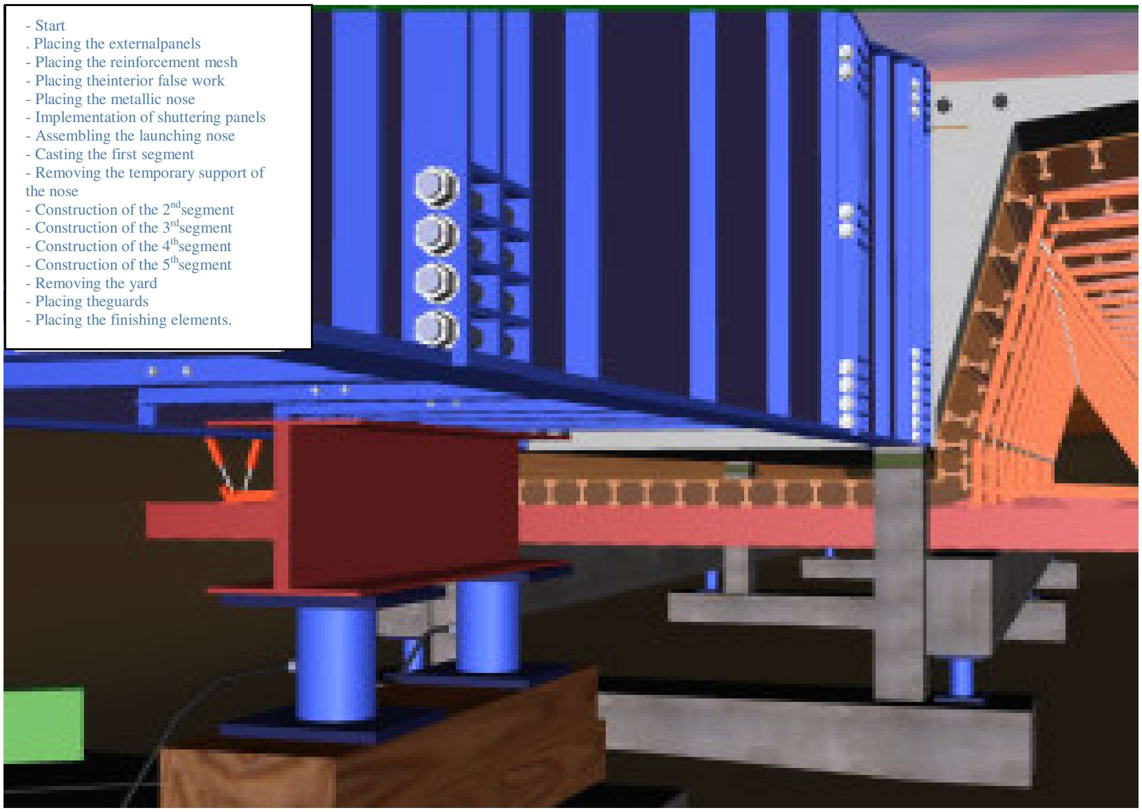
The camera movement shows the model in a consistent way to present all sequences of events allowing the user to perceive correctly the most important details of this construction method. Figure 10 illustrates the transposition process of the pier by the nose. In it, the small brown parallel pipe is the launch pads and is placed manually by workers between the nose and the temporary support placed over each pier. The camera is positioned to show properly the work. This phase of the animation is programmed to run various actions at the same time, adequately synchronized.

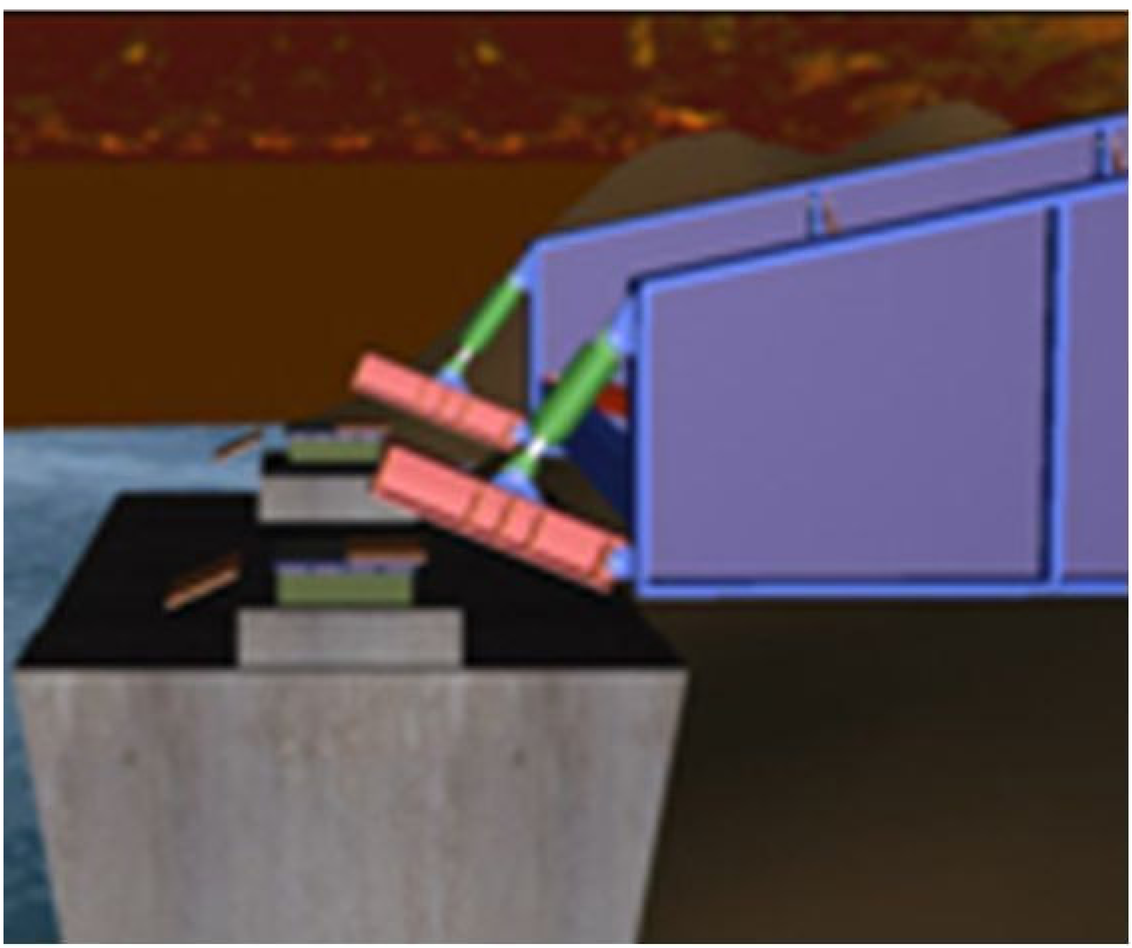
The roof model is an educational application to support the discipline Computer Aided Drawing. The issues involved require spatial awareness which, in traditional methods of teaching is transmitted through plane view. This application supports the explanation of topics related to the construction of both simple roofs and more complex ones (that is, those that are more difficult for students to grasp). The model shows, in an animated way, the intersection between two simple roofs defining a more complex one (Figure 11).

Conclusions

It had been demonstrated, through the didactic examples, how the technology of virtual reality can be used in the elaboration of teaching material with educational interest in the area of construction processes. The main objective of the practical application of the model is to support class-based learning. In addition, it can be used in distance training based on e-learning platform technology. The involvement of virtual reality techniques in the development of educational applications brings new perspectives to Engineering education. The student can interact with the virtual models in such a way that he can set in motion the construction sequence demanded by actual construction work and observe the methodology applied and analyze in detail every component of the work and the equipment needed to support the construction process. There are many other possibilities for the creation of computational models mainly where the subject matter is suitable for description along its sequential stages of development. The applications with these characteristics make the advantage of using techniques of virtual reality more self-evident, especially when compared to the simple manipulation of complete models which cannot be broken down. So, the advantage of introducing new technologies and didactic material suitable for university students and technical education should be made known and applied.

In rehabilitation, the papers also show how 3D models could be an important tool for the survey of structural anomalies and for the aesthetic evaluation of alternative solutions. Two situations were analyzed. The rehabilitation of one building concerns structural elements and in the second case new sanitary equipment was installed. In both examples, the 3D models were created in order to better describe the structural organization and anomalies and to evaluate different structural rehabilitation choices according to parameters such as the damage caused to the old structure, the historic elements preserved and the aesthetic values.


- Start
. Placing the externalpanels
- Placing the reinforcement mesh
- Placing theinterior false work
- Placing the metallic nose
- Implementation of shuttering panels
- Assembling the launching nose
- Casting the first segment
- Removing the temporary support of the nose
- Construction of the 2nd segment
- Construction of the 3rd segment
- Construction of the 4th segment
- Construction of the 5th segment
- Removing the yard
- Placing theguards
- Placing the finishing elements.



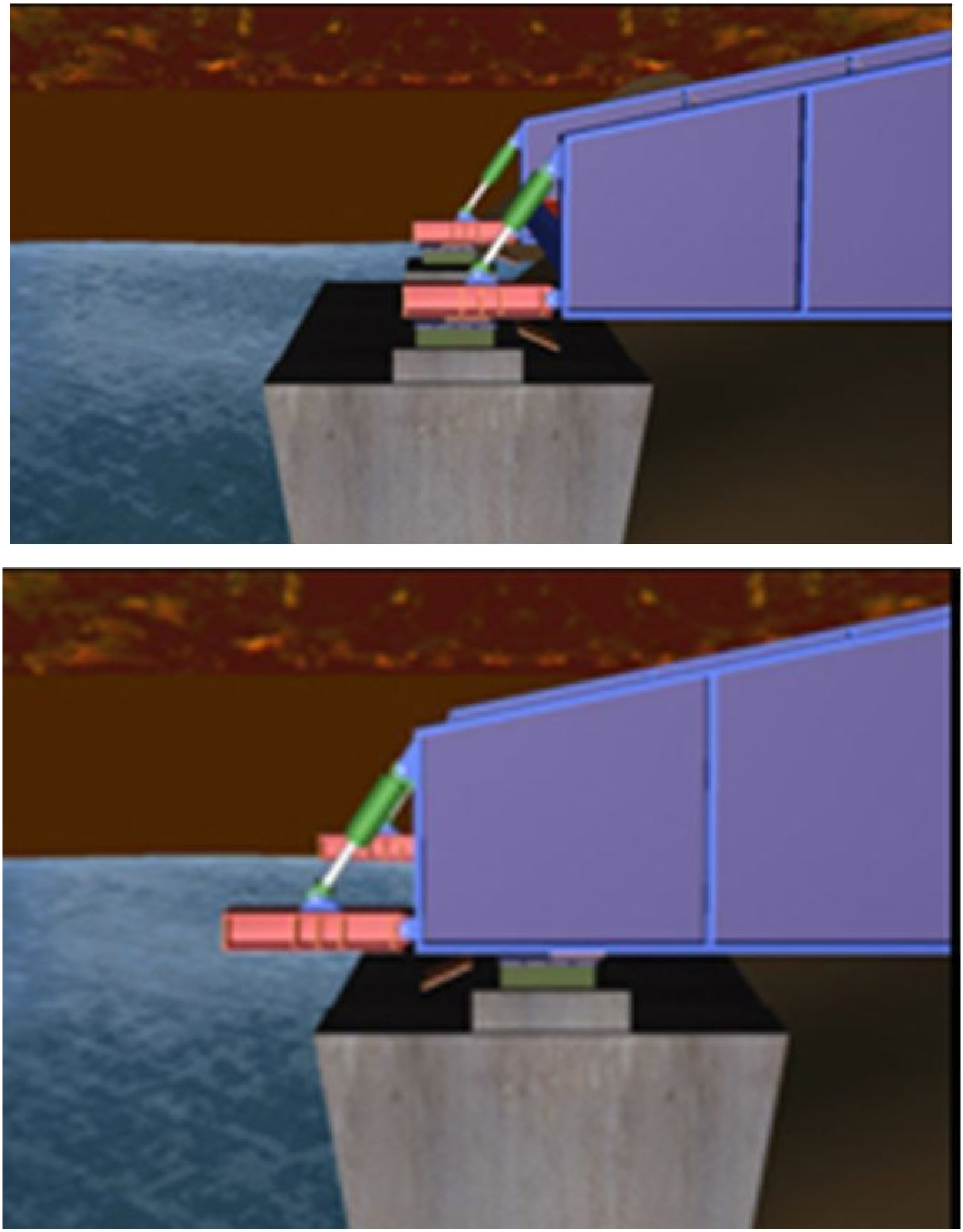


Figure 10. A menu of events displayed and the nose arriving at a pier process.

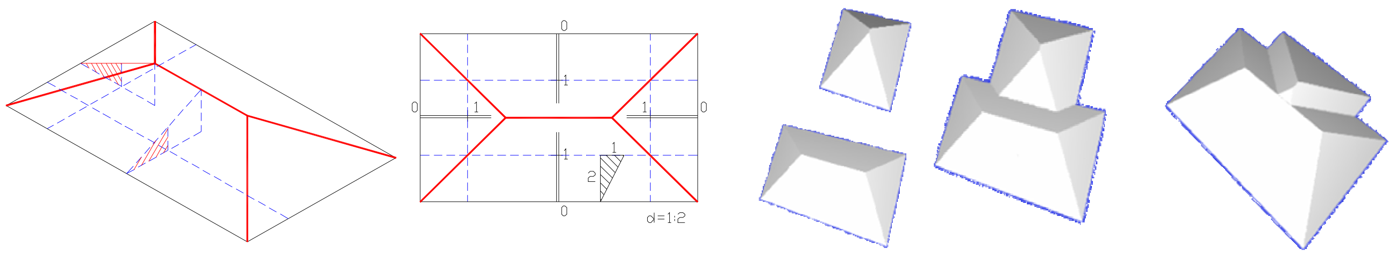


Figure 11. A perspective, a plane view and sequence of the RV roof model.

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