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Building Bridges Activity within a Virtual Environment

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1. Introduction

In the execution of bridge or overpass decks several construction processes are applied. A geometric model 4D (3D+time) in a Virtual Reality (VR) environment which simulates the construction of a bridge deck composed of precast beams was implemented. The model allows viewing and interaction with the various steps and the main elements involved in the construction process. In order to develop the virtual model, the components of the construction, the steps inherent in the process and its follow-up and the type and mode of operation of the required equipment were initially examined, in detail. Based on this study, the 3D geometric modelling of the different elements that make up the site was created and a schedule that would simulate an interactive mode of construction activity was established. As the model is interactive, it allows the user to have access to different stages of the construction process. It allows different points of view in time and in space throughout the development of construction work, and thereby it supports the understanding of this constructive method. Since the model is didactic in character it can be used to support the training of students and professionals in the field of Bridge Construction. The VR application is currently used to support Bridge classes at the Department of Civil Engineering of the University of Lisbon.

In Civil Engineering, there are several construction methods for the execution of bridge decks. This study analyses the constructive method applied to bridge decks using precast beams. In Civil Engineering prefabricated elements are frequently used, because they offer several advantages in urban areas. Namely it is applied in works over railway lines, and in general in areas where the placement of trusses is difficult, as this allows quick and economical construction without generating significant local constraints.

This present work aims to contribute to the dissemination of this methodology of construction through a visual simulation created in a virtual environment. It also draws attention to its usefulness as a teaching tool, supporting, as it does, the in-depth understanding of

this process. For the creation of a visual simulation application Virtual Reality (VR) technology was applied. This technology offers advantages in communication allowing the user to interact with the 4D model as it allows access to different modes of viewing the model in space and time (Woksepp, 2007).

2. VR technology in education

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. When modelling 3D environments there must be a clear idea of what should be shown, since the objects to be displayed and the details of each must be appropriate to the goal the teacher or designer wants to achieve with the model. The use of virtual reality techniques in the development of these didactic applications is, also, generally beneficial to education in that it improves the efficiency of the models in the way it allows 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 3D space, and to repeat the sequence or task until the desired level of proficiency or skill has been achieved always performing in a safe environment. Therefore, it can be seen that VR technology applied to didactic models brings new perspectives to the teaching of subjects in Civil Engineering education (Sampaio & Henriques, 2008).

Currently, the information related to the construction of buildings is based on the planning of action to be taken and on the log of completed work. It is also applied in education. The capacity to visualize the construction activity can be added through the use of three-dimensional (3D) models which facilitate the interpretation and understanding of process sequence of construction. Furthermore, the possibility of interaction with the geometric models can be provided through the use of Virtual Reality (VR) technology. The developed VR models can be considered as useful computer tool with advanced visualization capacities in the education and construction fields. The interaction with the construction steps visualization allowed by the models turn these applications simple and direct to be used in an educational perspective.

The VR technology is actually used in areas like education as a teaching support tool or in planning processes concerning industry as a collaborative tool. In architectural design studio, Abdelhameed (2013) applies micro-simulation function, inside a virtual reality environment, using the VR Studio program, in order to provide the students with an effective tool to select and visualize a structural system and its construction process. Fillatreau et al. (2013) develop a framework for immersive industry checklist-based project reviews, combining immersive navigation in the checklist, virtual experiments and multimedia update of the checklist. The authors relied on the integration of various VR tools and concepts, in a modular way, and developed a set of learning activities for students, in the Engineering Graphics subjects, in order to acquire, develop and improve their levels of spatial skill. For that purpose; they have structured training with VR and Augmented Reality (AR) technologies. Menck et al. (2013)

uses VR as a tool for collaboration to exchange information and data has increased significantly over time in production-related areas.

The model discussed here follows other didactic VR models applied to the construction of bridge field developed within the University of Lisbon at the Department of Civil Engineering:

- One model presents the cantilever method of bridge deck construction, a frequent construction technique (Figure 1, Sampaio et al. 2005);
- Another model attends the incremental launching method of bridge deck construction (Figure 2, Sampaio & Martins, 2014).

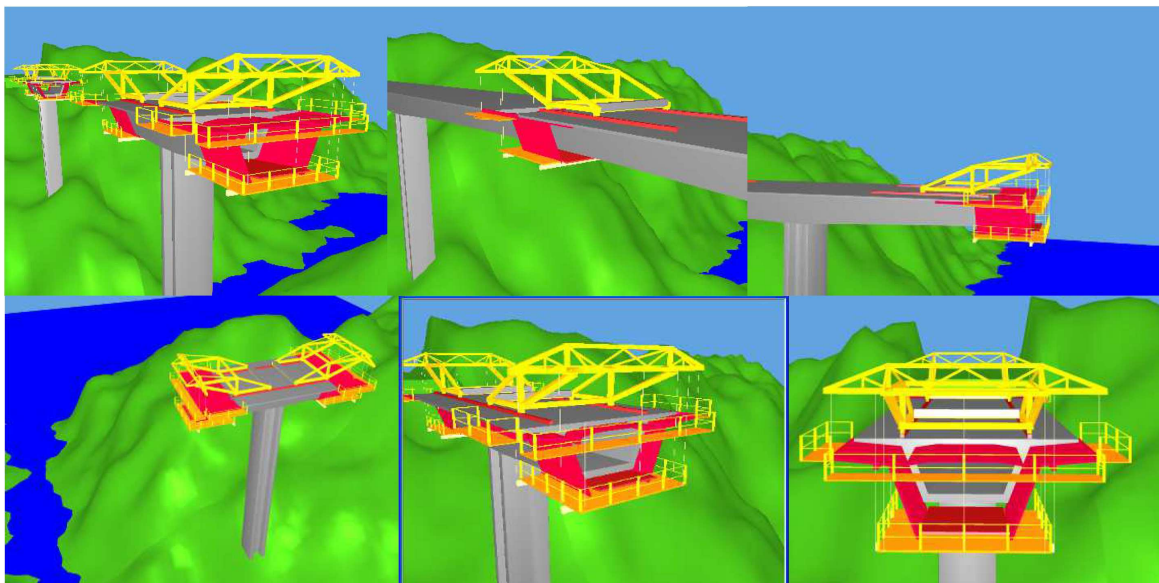


Figure 1. Virtual model of the cantilever process bridge deck construction.

The aim of the practical application of the virtual modes 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 (Birzina et al. 2012). 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. They also assist the study of the type and method of operation of the equipment necessary for these construction methodologies. Furthermore, the possibility of interaction with the geometric models can be provided through the VR technology capacities. The didactic VR models are actually in common use in both face-to-face classes and on an e-learning platform. In a real construction place of a bridge, for security reasons, the student stays far from the local where bridge is under construction, so they cannot 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 better understand what is going on there in the work place.

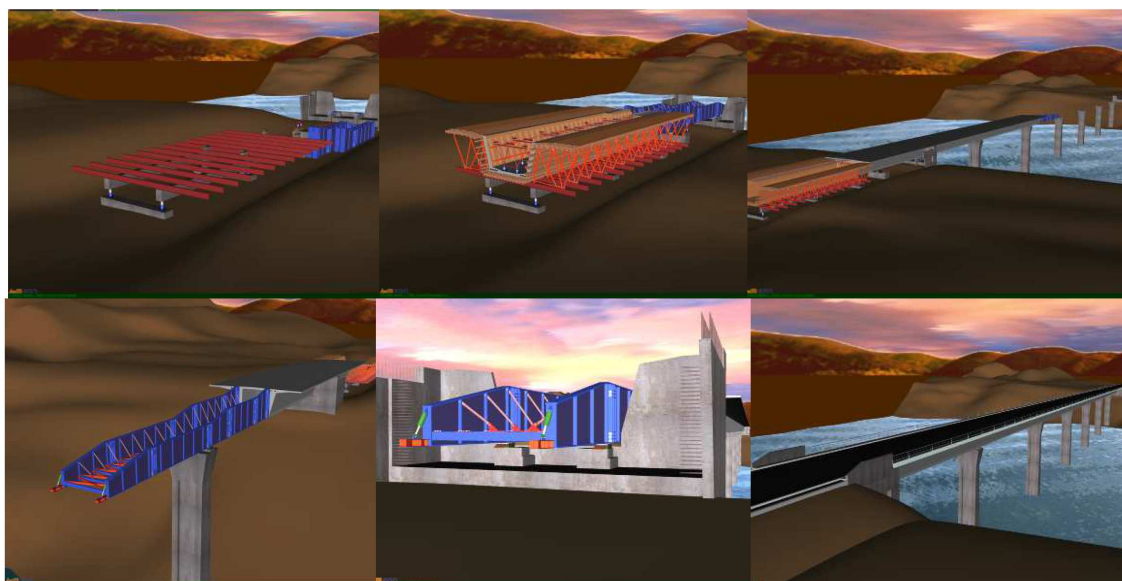


Figure 2. Virtual model of the incremental launching method of bridge deck construction.

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; 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. Specialist in construction processes and bridge design were consulted and implicated in the development of the educational models in order to obtain efficient and accurate didactic applications.

3. VR/4D models in construction

Information technology, namely 4D modelling and VR techniques, is currently in use both in the construction activity and in education (Mohammed, 2007). In construction industry, from the conception to the actual implementation, project designs are presented mostly on successive steps, even though the two dimensional reading is often not enough, as mistakes can be introduced in early stages of conception or elements misunderstood on the construction site. 3D models present an alternative to avoid inaccuracies, as all the information can be included with the necessary detail. Computer systems used in construction for graphic representation have experienced a vast evolution, allowing new ways of creating and presenting projects.

4D models, also labelled as 3D evolutionary models, permit a better comprehension of the project throughout its life, minimizing the information loss through the chain of events. A 4D

model combines 3D model with the appropriate scheduling data. Integration of the geometrical representation of the building together with scheduling data has been a topic for many research and development efforts. Different approaches for this integration are the following (contains links to the corresponding approaches) (Kähkönen & Leinonen, 2014). 4D models developed in CIFE (Center for Integrated Facility Engineering, of Stanford University) have shown the benefits and opportunities of visualizing construction information in a 4D (time +space) context. Today, 4D models visually describe how construction progresses. The opportunity, though, is to use the 4D medium to explain planning decisions and impacts of those planning decisions, making 4D models explanative and predictive (4D group, 2014). So, planners can contextually visualize various types of planning information to better support decision making.

In addition VR technology can present a step-by-step guide in assembling complex structures in an interactive way. One of the benefits of VR in construction is the possibility of a virtual scenario being visited by the different specialists, exchanging ideas and correcting mistakes. 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 models. 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. 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. Provided that the 3D model of the building progress is generated as construction progresses, this data can be used for the calculation of interim payments, schedule control and assessment, conflict management or avoidance purposes.

3D and 4D modelling are being used to improve the production, analysis, and management of design and construction information in many phases and areas of construction projects (Fischer & Kunz, 2004). 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 et al. 2013). Note also the contribution of VR in Architecture/Engineering, to support conception design (Petzold et al. 2007), presenting the plan (Khanzode et al. 2007) or following the progress of construction (Fischer, 2014).

Previous works in construction field of the author concerns other 4D applications based also on VR technology for use in construction and maintenance planning of buildings (Figure 3.):

- The 4D planning construction application considers the time factor showing the 3D geometry of the different steps of the construction activity, according to the plan established for the construction (Sampaio et al. 2011);

- The maintenance VR models were created in order to help in the maintenance of painted interior walls and facades in a building. It allows the visual and interactive transmission of information related to the physical behaviour of the elements. To this end, the basic knowledge of material most often used in coverings, anomaly surveillance, techniques of rehabilitation, and inspection planning were studied. This information was included in a database that supports the periodic inspection needed in a program of preventive maintenance (Sampaio et al. 2012).

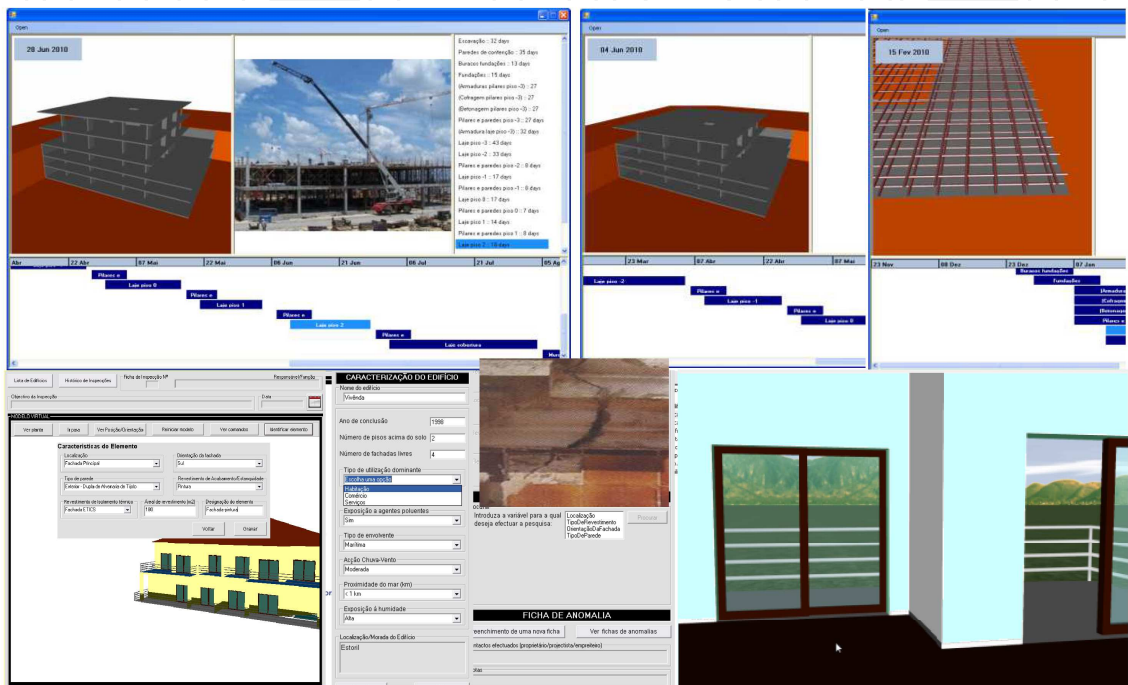


Figure 3. VR models of construction and coating elements of exterior and interior walls.

This work brings an innovative contribution to the field of construction and maintenance supported by emergent technology. The building lifecycle is in constant evolution, so require the study of preventive maintenance, though, for example, the planning of periodic local inspections and corrective maintenance with repair activity analysis. For this reason, the VR models facilitative the visual and interactive access to results, supporting the drawing-up of inspection reports. The focus of the work is on travelling through time, or the ability to view a product or its components at different points in time throughout their life. In maintenance, the time variable is related to the progressive deterioration of the materials throughout the building's lifecycle.

4. Bridge decks composed of prefabricated beams

Using prefabrication in bridges presents several advantages, such as (Câmara, 2001): the good quality of the concrete of the components produced; economic benefits that result from the use

of optimized and standard solutions, which can be used repeatedly throughout the whole process; reduction of congestion on the construction site and the shortening of time-limits for construction, and finally, greater security because it reduces the number of tasks to be carried out on site.



Figure 4. Overpass on A23 performed with prefabrication (Juntas, 2013)

The construction of bridge decks composed of prefabricated beams uses an equidistant distribution of isolated elements placed side by side, complemented by a slab that establishes continuity on the surface of the deck. The prefabricated beams are usually built with a length equal to the bridge spans, each consisting of several beams connected from above by a slab concreted “in situ”, and crosswise by transversal beams located on the support.

The slab can be made “in situ” using a false-work or pre-slabs, which can contribute to structural strength or assist only as formwork while the slab of the deck is concreted. The most common cross sections in these types of beams are I-shaped (Figure 5) or, sometimes, U-shaped. The shape of the section is determined by various constraints, such as: the procedure of manufacture; the pre-stressing system used (pre-or post-tensioned); transport and assembly; the construction method of the bridge deck slab.

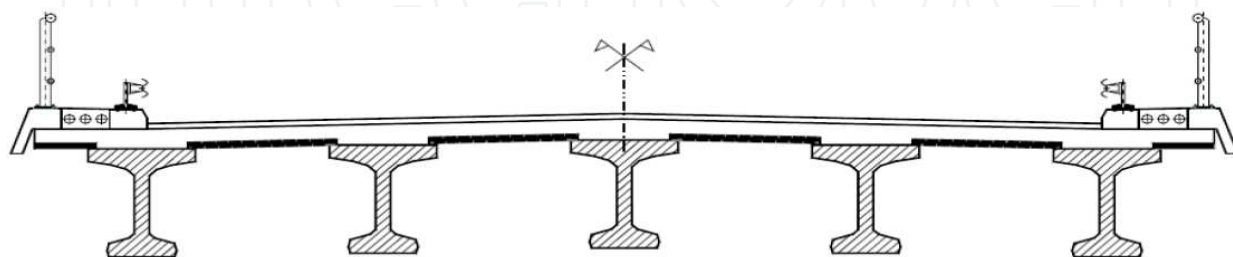


Figure 5. Cross section of a bridge with "I" beams (Sousa, 2004).

The constructive method applied to bridges with prefabricated beams can include differences in placement of prefabricated beams, or the type of connection between elements and execution

of slabs. The first step consists of placing the prefabricated beams, which can be carried out by means of cranes a launcher (Figure 6).



Figure 6. Placing of precast beams on the pillars (Leonhardt, 1982).

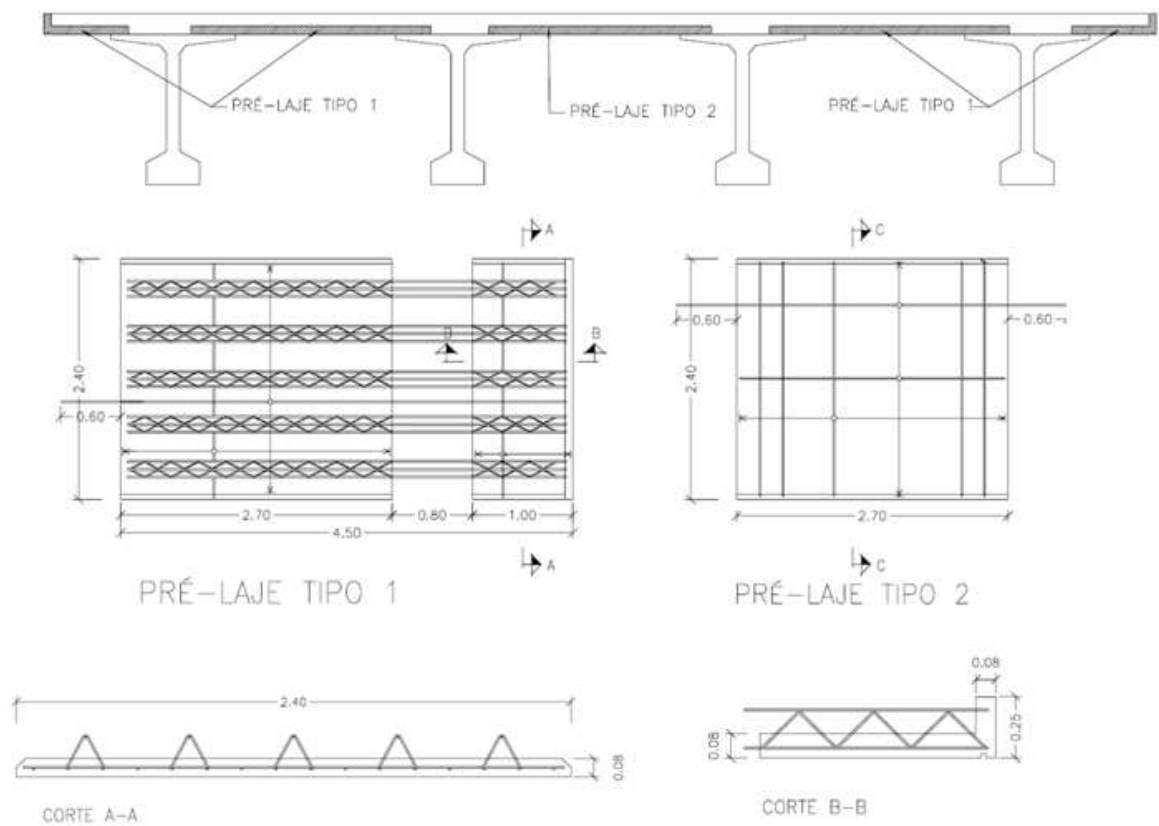


Figure 7. Reinforced pre-slabs used as lost shuttering.

After placing the prefabricated beams in their final position, the connection between these elements is performed using pre-slabs: This method consists of replacing the shuttering and supporting structure of the previous solution for reinforced concrete or pre-stressed slabs with a thickness that usually varies between 6 cm and 10 cm. These pre-slabs can be used as lost shuttering (Figure 7), in construction they can be used only to support the concrete slab or as bi-functional formwork, that is, functioning as formwork during the constructive phase, but as reinforcement during service.

5. 4D didactic model

5.1. Geometric modelling and equipment

After different kinds of bridge deck construction methods had been analysed, a commonly used model was chosen for the implementation of the 4D (3D+time) virtual model (Viana, 2012). The deck is composed of beams with I-shaped cross section, lifted by cranes and supplemented with composite pre-slabs. Initially, three-dimensional (3D) geometric modelling of all elements necessary to the implementation of the desired visual simulation was created. The example modelled corresponds to a bridge with the highway profile composed by five spans with the extension of 30m (central) and 24m (lateral) (Reis, 2006). The cross-section of the bridge deck consists of 4 precast beams (Figure 5).

The 3D modelling process is initiated with the generation of the surroundings of the working place, followed by the pillars, stair towers, worker platforms, provisional and definitive supports and two cranes needed to lift the precast beams (Figure 8).

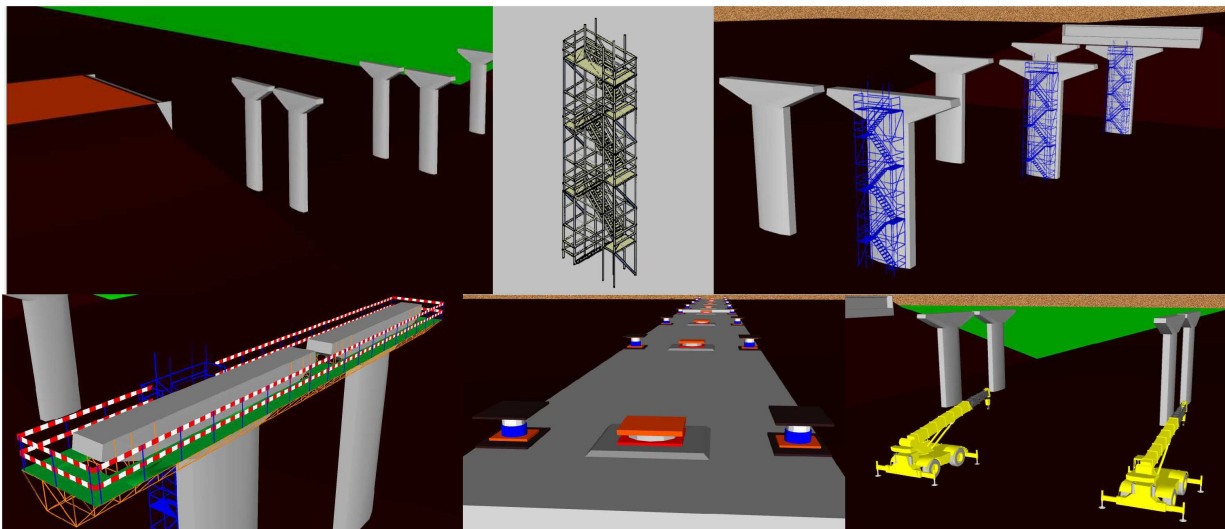


Figure 8. 3D models of the construction environment.

Figure 9. represents the configuration of the cross-section of the prefabricated beam used and the respective 3D model. In the projection it is possible to see: the running boards (red),

protruding out of the beam, which serve to provide resistance and support for the connection of concrete of different ages of the deck slab; the reinforcements connecting precast beams (yellow); other reinforcements needed for lifting the beam (blue).

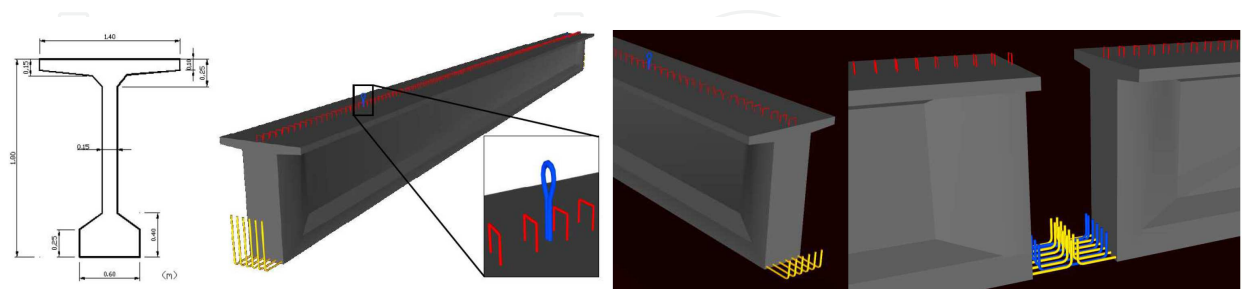


Figure 9. Cross-section and prefabricated beam model.

For the execution of the slab composite pre-slabs were chosen. The dimensions applied in creating the 3D model of the pre-slabs were established based on the drawings of the design of Beira Interior viaducts. Differentiation can be made between pre-slabs, depending on their location on the cross-section: type 1, between beams or type 2, in the console. Figure 10 shows a picture of the placement of both types of pre-slabs. The virtual model includes two types of pre-slabs: central and cantilever. Figure 10 illustrates the geometric model of two kinds of pre-slabs used in the virtual model. The pre-slab in the console is placed in the side of the deck cross-section and the central pre-slab is placed between beams.

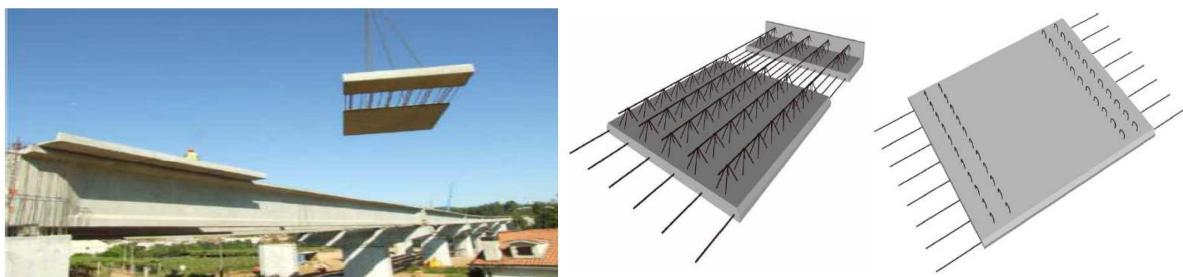


Figure 10. 3D models and placement of pre-slabs on the deck.

5.2. The constructive process activity

The visual simulation of the construction was accomplished using software based on the Virtual Reality (VR) technology, the Eon Studio (EON, 2013). In the application, the geometric model of the building is presented in a sequence simulating the construction activity. For that,

each modelled component of the bridge is connected to the programming instruction: hidden and unhidden (Figure 11).

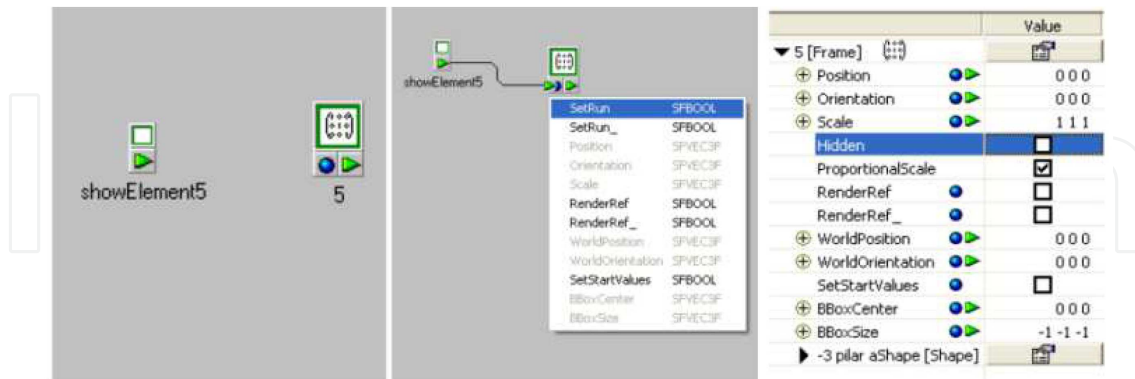


Figure 11. Hidden and unhidden instruction in the interface of the EON software.

This is one of the capacities allowed by the EON software. The command of unhide is first linked to each geometric model. An action will begin when the user click over an unhidden object and then the next object is visualized in the virtual environment, in accordance with the established sequence of the construction:

- The virtual simulation starts with the presentation of the work place environment;
- The simulation of the construction activity continues with the insertion of additional elements, such as the stair towers (for access to the top of the pillars) and the work platforms (which allow the workers to move around and complete their tasks) (Figure 12).

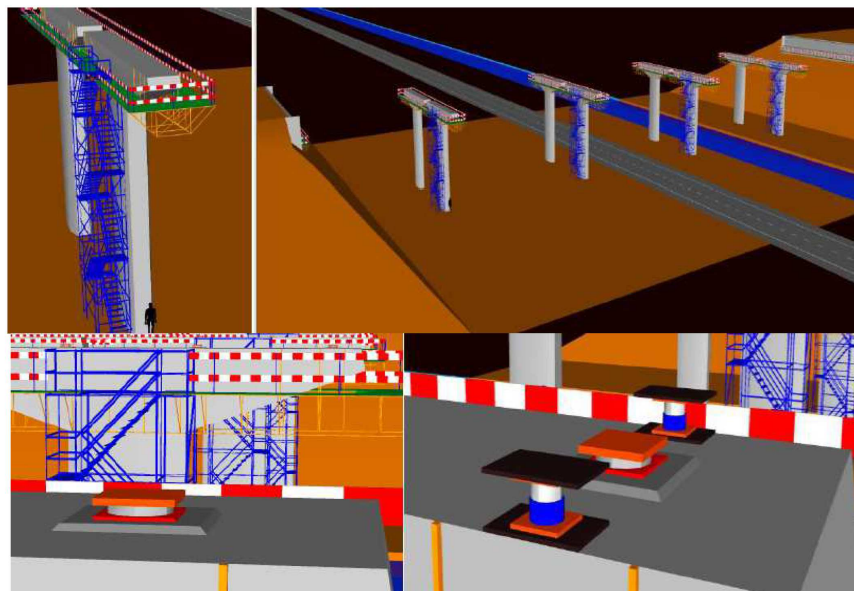


Figure 12. Display stair towers, work platforms and definitive and provisional supports.

- In the virtual space the placing of the definitive support device is simulated, followed by the placement of the temporary support, on the top of the pillars (Figure 12);
- Each beam is raised by two cranes and placed on the temporary support devices (Figure 13);



Figure 13. Prefabricated beams raised by two cranes.

- The simulation of construction process proceeds with the placement of the pre-slabs over the prefabricated beams (Figure 14). At this stage, it was found that due to the large amount of reinforcements set in the pre-slabs, the movement of the camera (from the point of view of the user) through the virtual environment was very slow because the drawing file was already too heavy. It was, therefore, decided not to display 3D model of the pre-slab reinforcements and also the brackets from prefabricated beams;

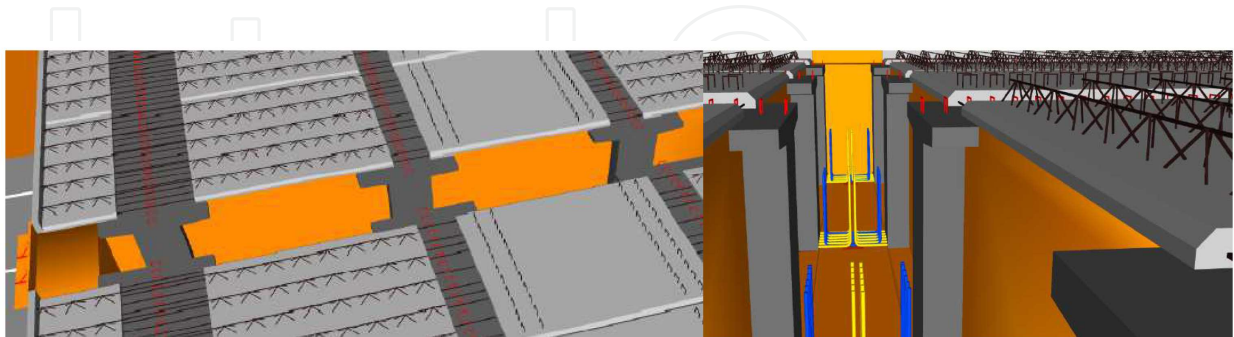


Figure 14. Placement of pre-slabs over the prefabricated beams.

- Then, the reinforcement of the slab is placed over the pre slabs and the deck slab is concreted (Figure 15);

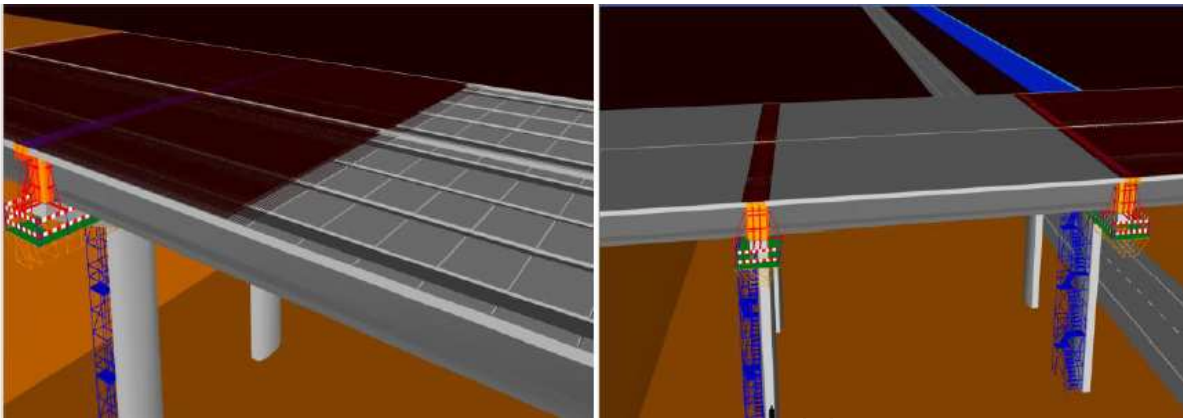


Figure 15. Placing reinforcement and concreting the deck slab.

- Next, the transversal beams are concreted. Figure 15 illustrates the placement of the formwork and reinforcement of one of the transversal beam;

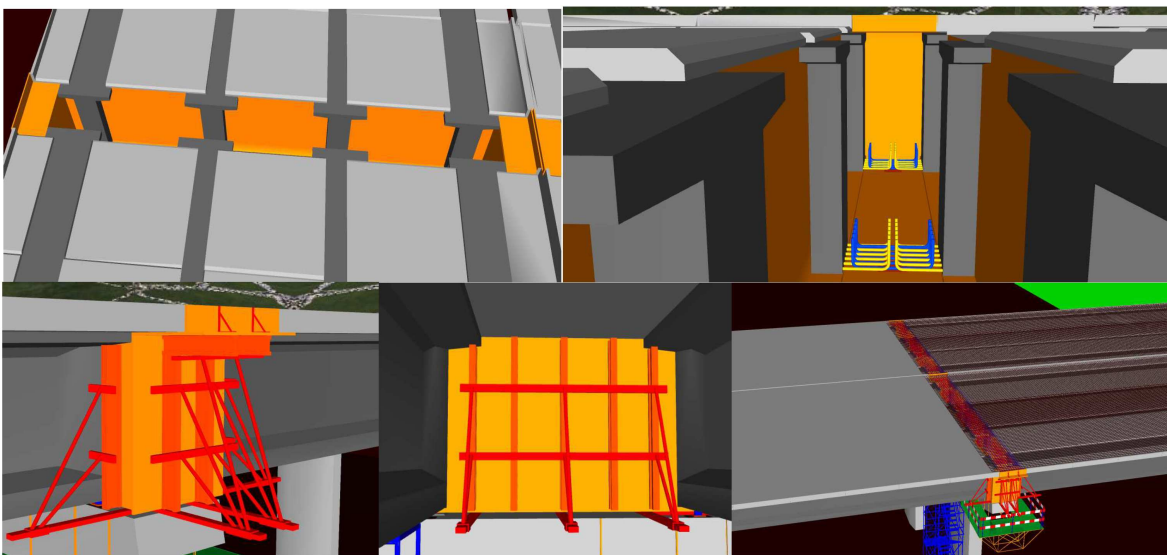


Figure 16. Removing the provisional support devices.

- After the completion of the construction of the deck the provisional support devices are removed (Figure 17);
- Finally all complementary elements necessary for the road traffic were inserted into the top of the deck (Figure 18).

The complete bridge can now be observed from any point of view (Figure 18). The model allows the user to use the zoom sufficiently well in order to understand the final configuration of the bridge. The animation of the VR application can be visualized in the a web site (Luiis, 2013).

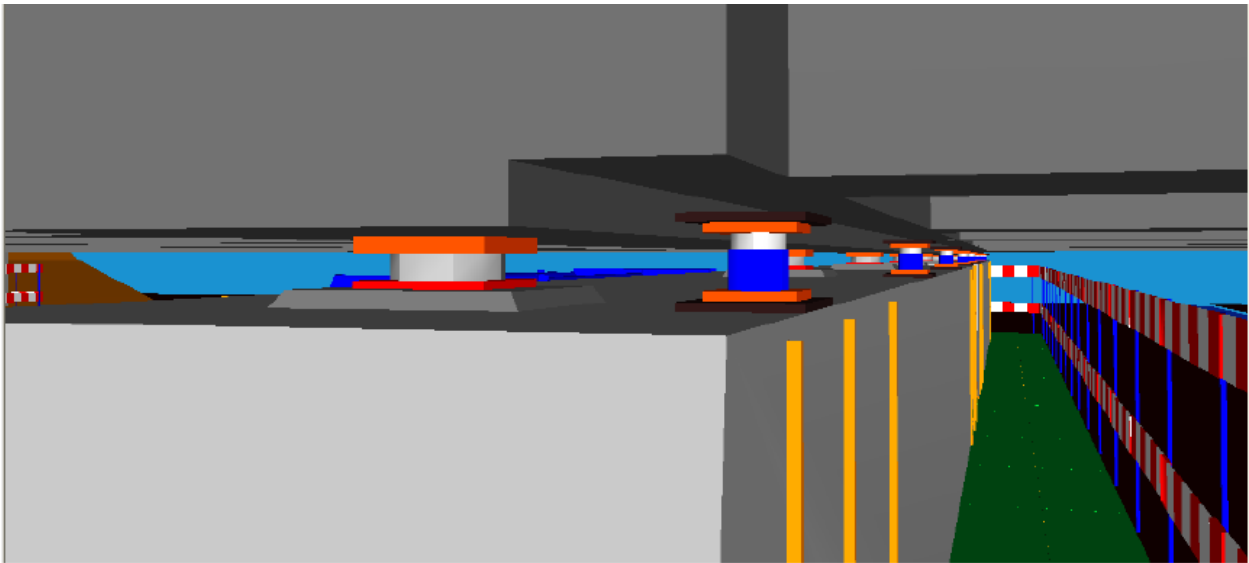


Figure 17. Removing the provisional support devices.

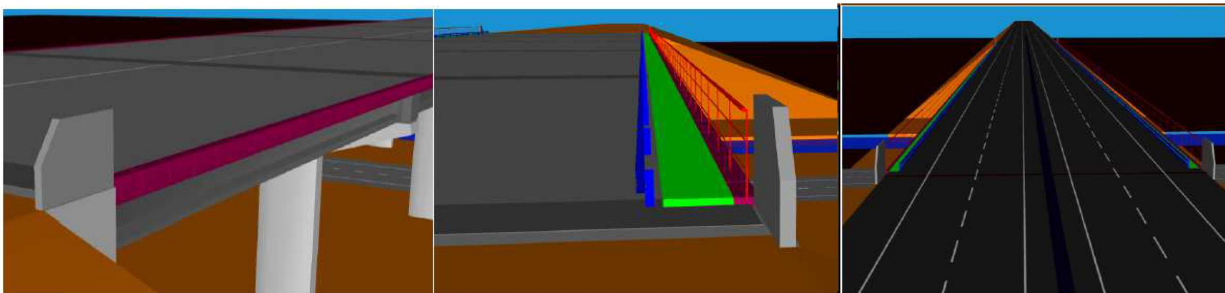


Figure 18. Placing the complementary elements off the deck

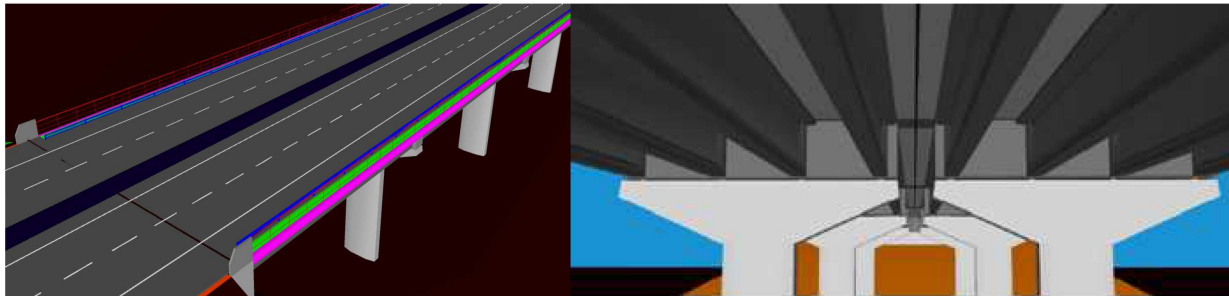


Figure 19. Views of the complete deck

6. Didactic aspects

The main objective of the practical application of this didactic model concerning a bridge construction process is to support class-based learning and in distance learning using e-

learning technology. A didactic application to be used as an e-learning tool must meet the following requirements: reusability, accessibility, durability and interoperability (Birzina et al. 2012). Thus, it seeks the same educational database for be used by the international community through different learning software. Furthermore, it is necessary employ an accepted format with the aim of facilitate communication between different databases of several areas of knowledge. Also another important point to be considered is those models in e-learning institutions should be independent of country, language or any other regional circumstances in the process of creation the didactic models.

The bridge model is currently being used in face-to-face classes of disciplines of Civil Engineering curriculum: Construction Process (4th year) and Bridges (5th year). They were placed on the webpage for each discipline thus being available for students to manipulate. The student should download the EON Viewer application available at the EON web site. 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. Through direct interaction with the models, it is possible to monitor the progress of the construction process of the bridge. The objective is not to replace current training methods but to position accurate as an additional teaching method. To do so, there were developed immersive 3D models that were based on an actual method of teaching.

The deck bridges model shows the complexity associated to the construction work of the deck. The model also illustrates in detail the movement of the equipment. In class, the teacher must explain way the process must follow both sequence of steps and the way the equipment devices operates. When the student, of the 5th year, goes to a real work place he can observe the complexity of the work and better understand the progression of construction previously explained. It provides an immersive capacity inherent to virtual world and it allows the students and teachers to go to a specific construction step. 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;

The discipline of Bridges, offered to 5th year students of Integrated Master Degree in Civil Engineering, has a weight of 4.5 curricular credits. The general objectives of the Bridges discipline concerns an introductory course on bridge design and construction, the basic concepts for prestressed concrete bridges and steel-concrete composite bridges, the basic models for the analysis and design of bridge superstructures and substructures. The curricular program of the Bridges discipline contains the specific topic "Design concept and execution methods: superstructure concept; concrete bridge decks-slab, beam-slab and box girder decks; composite (steel-concrete) bridge decks; piers, abutments and foundations; construction methods", along 9 hour, (program, 2014). And the assessment process is based in a final examination (70%) and a work report (30%). The recommended bibliographies are essentially the didactic text of Reis (2006) and two main books concerning construction of bridges (Leonhardt, 1982) and (Calgaro & Virlogeux, 1987). The different construction methodologies that are available must be well known by the future designers, as it influences significantly the choice of most suitable solution of the deck typology, for each particular situation. So the

subject concerning bridge construction is of great importance in the discipline. The VR models became useful to teachers when they are presenting the distinct methodologies of constructing deck bridges. The interactive models are also an important support to students when writing the report of the discipline, as some students chose the construction processes topic to study. In these reports there are evident references to constructive details, to the sequence of activities and to the equipment needed to construct the bridges, aspects which are clearly presented in the virtual models. So the VR models have been contributing to a better understanding of the issue concerning bridge construction and also to motivate students to this specific topic.

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 own PCs. The animation of the construction process can then be visualized.

The didactic application of deck bridge construction was developed by the co-author L. Viana, as an engineering student, and supervised by the first author. This work complemented the author's skill concerning the use of the AutoCAD software. Along the course the engineering students learn how to use AutoCAD, mainly applied on the execution of 2D drawing and basic 3D models. L. Viana when generating the presented VR model increased their knowledge relating to the use of AutoCAD and learned how to use a new tool based on VR technology. Sik & Sik L. (2013) points that the knowledge of the 3D design and engineering software are indispensable for all kind of engineering activity (civil engineer, mechanical engineer, architecture and transportation engineering) and ask, among the students, about the necessity of learning AutoCAD in the faculty. The answer is naturally positive. The VR application presented in this chapter, complementing the AutoCAD training introduced at the 1st year, is in line with the point of view of those authors.

7. Conclusions

This paper analyses some constructive processes concerning bridge deck formed of precast beams and describes the implementation of an interactive model that simulates the construction work activity. The virtual application shows one of the methods most often applied in the construction of this type of bridge.

In the creation of the model software based on the Virtual Reality (RV) technology was used. VR allows, through interaction with 3D models of the environment, representing building components and equipment, the creation of the constructive sequence in time and space by simulating the progression of the construction of the deck, which allows a good understanding of the whole process.

The model 4D (3D+time) offers several advantages, allowing a deeper awareness of the relationship of the components of the building and the phasing of the work, leading to a better understanding of the spatial movement of equipment and of the component placement in

work. Since the traditional designs of graphic documentation of the construction project are sometimes more difficult to understand, it can be seen that this model is clearly didactic in character and as such can be used to support the training of students and professionals in the field of Bridges.

Author details

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References

- [1] 4D group (2014). 4D annotator: A visual decision support tool for construction planners, CIFE-Center for Integrated Facility Engineering, of Stanford University, <http://web.stanford.edu/group/4D/workspace/papers/cife-98prop2.pdf>, accessed: July, 2014.
- [2] Abdelhameed, W.A. (2013). *Virtual reality used in architectural design studios: A case of studying structure and construction*, Procedia Computer Science, Vol. 25, 2013, pp. 220-230.
- [3] Birzina, R.; Fernate, A.; Luka, I.; Maslo, I.; & Surikova, S. (2012) E-learning as a challenge for widening of opportunities for improvement of students' generic competences, journal E-Learning and Digital Media, ISSN 2042-7530, 01/2012, vol. 9 (2), pp 130-142.
- [4] Calgaro, J.; & Virlogeux, M. (1987) *Project et construction des ponts*, Presses de l' cole Nationale des Pontes et Chauss es, Vol I
- [5] C mara, J.N. (2001). Prefabrication of bridges and viaducts, didactic text, Lisbon, Portugal. <http://www.civil.ist.utl.pt/~cristina/EBAP/PreFabricacaoEstruturas/Pontes%20e%20viadutos.pdf>, accessed: July, 2014
- [6] EON (2013). Introduction to working in EON Studio, EON Reality, Inc., <http://www.eonreality.com/>. accessed: July, 2014.
- [7] Fillatreau, P.; Fourquet, J.-Y.; Cailhol, R.M.; Le Bolloc'h, S.; Datas, A.; & Puel, B. (2013). Using virtual reality and 3D industrial numerical models for immersive interactive checklists, Computers in Industry, Volume 64, Issue 9, Dec. 2013, pp. 1253-1262.

- [8] Fischer, M. (2000) 4D CAD-3D Models incorporated with time schedule, CIFE-Centre for Integrated Facility Engineering in Finland, VTT-TEKES, CIFE technical report, Helsinki, Finland.
- [9] Fischer, M.; & Kunz, J. (2004) The scope and role of information technology in construction, in: CIFE Centre for Integrated Facility Engineering in Finland, technical report #156, Stanford University.
- [10] Juntas, P. (2013). Picture CC-BY-SA-2.5, <http://creativecommons.org/licenses/by-sa/2.5>, accessed: June, 2014.
- [11] Kähkönen, K.; & Leinonen, J. (2014) VTT Building and Transport VTT, Finland, <http://cic.vtt.fi/4d/4d.htm>, accessed: July, 2014.
- [12] Khanzode, A.; Fisher, M.; & Reed, D. (2007). Challenges and benefits of implementing virtual design and construction technologies for coordination of mechanical, electrical, and plumbing systems on large healthcare project, in: CIB 24th W78 Conference, Maribor, Slovenia, pp. 205-212.
- [13] Leinonen, J.; Kähkönen, K.; & Retik, A. (2013) New construction management practice based on the virtual reality technology. In Raja R.A., Flood I, William J, O'Brien (Ed.), 4D CAD and Visualization in Construction: Developments and Applications, A.A. Balkema Publishers, pp. 75-100.
- [14] Leonhardt, F. (1982) Concrete constructions – basic principles of construction of concrete bridges, Vol 6, Ed. Interciência Rio de Janeiro, Basil.
- [15] Luiis (2013) <http://www.youtube.com/watch?v=zSIRXL64HnQ&feature=youtu.be>, accessed: July, 2014
- [16] Menck, N.; Weidig, C.; & Aurich, J.-C. (2013). Virtual reality as a collaboration tool for factory planning based on scenario technique, Forty Sixth CIRP Conference on Manufacturing Systems 201, Procedia CIRP, Vol. 7, 2013, pp. 133-138.
- [17] Mohammed, E.H. (2007). n-D Virtual Environment in Construction Education, Proc. the 2nd International Conference on Virtual Learning, ICVL 2007, pp. 1-6.
- [18] Petzold, F.; Bimber, O.; & Tonn, O. (2007). CAVE without CAVE: on-site visualization and Design Support in and within existing building, in: eCAADe 07, 25th Conference of Education and Research in Computer Aided Architectural Design in Europe, Frankfurt, Germany, pp. 161-168.
- [19] Program (2014), <https://fenix.tecnico.ulisboa.pt/disciplinas/Pon25/2014-2015/1-semester/program>, accessed: July, 2014
- [20] Reis, A.J. (2006). Bridges, Didactic text, Technical University of Lisbon, Lisbon, Portugal.
- [21] Sampaio A.Z., Santos J.P., Gomes A.R., Rosário D.P. (2012). Construction and maintenance planning supported on virtual environments, Book: Virtual Reality-Human

- Computer Interaction, Ed. Xin-Xing Tang, Publisher: InTech, Published: September 05, 2012, ISBN 978-953-51-0721-7, DOI: 10.5772/46409, ch. 07, pp. 125 – 152. <http://www.intechopen.com/articles/show/title/construction-and-maintenance-planning-supported-on-virtual-environments>, accessed: July, 2014.
- [22] Sampaio A.Z.; Cruz C.O.; & Martins, O.P. (2011). Didactic models in Civil Engineering education: Virtual simulation of construction works, Book: Virtual Reality, Ed. Jae-Jin Kim, ISBN: 978-953-307-518-1, Publisher: InTech, Copyright: Janeiro 2011, ch. 28, pp. 579 – 598, <http://www.intechopen.com/articles/show/title/didactic-models-in-civil-engineering-education-virtual-simulation-of-construction-works>, accessed: July, 2014.
- [23] Sampaio, A.Z.; & Henriques, P.G. (2008). Virtual reality technology applied to the visual simulation of construction activities, The Open Construction & Building Technology Journal, Mathew Honan, Editorial Director, Bentham Science Publishers Ltd., vol. 2, pp. 7-14.
- [24] Sampaio, A.Z.; & Martins, O.P. (2014). The application of virtual reality technology in the construction of bridge: The cantilever and incremental launching methods, Automation in Construction, Vol. 37, January 2014, pp. 58-67. <http://www.youtube.com/watch?v=S3Kf9e6JgF4>, accessed: July, 2014.
- [25] Sampaio, A.Z.; Henriques, P.G.; Studer, P.; & Luizi, R. (2005). Interaction with virtual 3D models in order to access the construction processes of a wall and a bridge, in B.H.V. Topping, (Editor), Proceedings of the Tenth International Conference on Civil, Structural and Environmental Engineering Computing – CC 2005, Rome, Italy, Civil-Comp Press, Stirlingshire, UK, Paper 79, abstract pp. 185-186, 2005. doi:10.4203/ccp.81.79, accessed: July, 2014.
- [26] Sik G.; & Sik Lanyi C. (2013) Is necessary to teach 3D design and engineering software for engineering students or the knowledge of these software are required skills?, Journal of Applied Multimedia 1(8), pp. 17-24, http://www.jampaper.eu/Jampaper_H-ARC/2013._VIII._1.sz._files/JAMPAPER130103e.pdf, accessed: July, 2014
- [27] Sousa, C.F.F. (2004). Structural continuity in bridge decks built with prefabricated beams. Solutions with reinforced concrete connection. MSc thesis in Civil Engineering Structures, FEUP, Porto, Portugal.
- [28] Viana, L.F. (2012). Simulation of the construction of the bridge deck composed of prefabricated beams based on Virtual Reality technology. MSc thesis in Civil Engineering Structures, IST, Lisbon, Portugal.
- [29] Woksepp, S. (2007). Virtual Reality in Construction. Tools, Methods and Processes, PhD thesis in Civil Engineering, Luleå University of Technology, Sweden.

