A Model to Distinguish Between Educational and Training 3D Virtual Environments and its Application

Marcelo da S. Hounsell[1], Edgar L. da Silva[1], Manoel R. Filho[2] and Marcos P. A. de Sousa[2]

[1]*LAboratory for Research on Visual Applications (LARVA), State University of Santa Catarina (UDESC), Computer Science Department (DCC), Campus Universitário S/N, CEP 890233-100, Joinville, SC, Brazil.*
[2]*Federal University of Pará (UFPA), Computing and Electrical Engineering Department, Rua Augusto Correa No. 1, CEP 66.000-000, Belém, Pará, Brazil.*

Abstract—**This paper proposes a model to identify education and/or training emphasis for 3D Virtual Environments. Through a survey of such applications specific characteristics of each emphasis were identified. Although few authors highlight the distinction between Virtual Environments for Education and Training, the correct definition of each of these types can facilitate the attainment of educational goals for the niche one wants to accomplish. In this study a special focus is given to the training applications, with the proposal of a standardization of the "training modes" based on a functional conceptual framework. At the end of the article a case study of a desktop Virtual Reality (VR) system for training will be presented. This system includes a maintenance sub-system in a Hydroelectric Energy Unit, using a "learn by doing" approach.**

Index Terms— **Education, Training, Virtual Reality, Hydroelectric Energy Unit.**

I. INTRODUCTION

The increase in complexity of technical equipment and machines in industry demands a greater periodicity and higher level of employees' qualification. The rising costs and efforts required to qualify the technicians make training centers seek new methods and tools to carry out training with fewer investments. There are additional reasons and requirements that demand the use of innovative training in the technical domain, such as [33]: the need of a training system that can be integrated to the working environment; the possibility of a training that can be offered globally and on demand; the use of adaptive training techniques, that may be offered efficiently and with the right engagement for the needs of the end user; the offering of a flexible training anywhere and anytime and; the integration of pedagogical aspects and human factors in the training environment to aid the end user in achieving the desired learning effects and results.

There are several reasons to use Virtual Reality (VR) in the teaching process, among them are [26]: greater motivation for the apprentice; the power of VR illustration to some processes and objects are far greater than other media; it allows a close up or distant analysis; it gives opportunities for experimentation; it does not restrict the experiences only to the moment of regular classes; it promotes interaction stimulating active participation of the apprentice, etc.

Experiments have shown that learners tend to spend twice as much time engaged in VR than using 2D multimedia instructional materials [16]. This fact reflects on absolute higher performances on object and sequence identification although no statistically significant difference in skills decay was observed in this specific study.

Among the applications of Teaching & Learning Virtual Environments (TLVE), two types of systems can be distinguished: virtual environments aimed at education (**EVE** – Education-oriented Virtual Environment) and virtual environments aimed at training (**TVE** - Training-oriented Virtual Environment). In the literature, not much distinction has been made between these two types, and there is still no agreement in the debate about these two emphases, but there is consensus that they are two distinct approaches. Recognizing the distinction and the characteristics that identify each emphasis may lead to the use of specific and proper VR techniques that facilitate achieving the teaching objectives.

Education and training are different aspects of the same spectrum. Conceptually, education is a wider way of learning whereas training is more specific. The former refers to the human being as a whole and prepares one to life, but training aims to prepare the worker for a particular task [7]. Education is a way of spreading and democratizing knowledge continuously, while training is understood as a short term educational process that uses a systematic and organized procedure, through which one acquires knowledge and technical skills for a specific purpose. Therefore, it can be defined that EVEs should enable the apprentice to learn how to learn, where the apprentice can analyze and ponder about the focus of study, and everything it includes. On the other hand TVEs should provide a specific learning with a fixed time-span that seeks to obtain innate abilities for the execution of tasks that are well delimited by the environment.

In recent years, the industrial Maintenance and Training areas have been the subject of study involving VR, which has a great potential in the training sector, as mentioned previously. This potential of VR is motivated by the good experiences of applications, such as: visualization of complex and extensive

Manuscript received on December 3 2008.
E-mail: marcelo@joinville.udesc.br

virtual environments [4,8]; use in assembly processes [18,32,40] and; training applications based in the learning by doing approach [2,15,21,22,36]. The latter includes two key elements: the self experience made possible by the environment simulation in the real world (using a 2D graphical interface, VR or both), and the training guide provided by the act of "following the steps" of the instructor.

During this research, VR applications aimed at both immersive and non-immersive training were found. Although immersive applications offer a higher level of interactivity and realism, they present hardware and software higher costs as well limiting its use and popularity. In addition, the ergonomics of most of the non-conventional devices is still a great problem to make immersive VR a widely accepted tool among users and researchers [39].

The objective of this paper is to identify a minimal and significant set of concepts that best characterize and distinguish EVEs from TVEs, detailing possible training modes on TVEs, and present a case study related to the assembly and disassembly procedures in a Hydroelectric Energy Unit (HEU), through a Desktop VR system.

In section 2 the categorization features for EVE and TVE are proposed, section 3 deepens in the aspects of VR in training, and on section 4 TVEs training modes are defined. On section 5 the case study is detailed followed by a discussion on the maintenance sub-system and finally, the conclusion finishes this text.

II. CHARACTERISTICS OF "EVE" AND "TVE"

Based on a survey of education-oriented and training-oriented Virtual Environments, some categories of features that best distinguish EVE and TVE were identified, and thereafter can guide the conception of Virtual Environments.

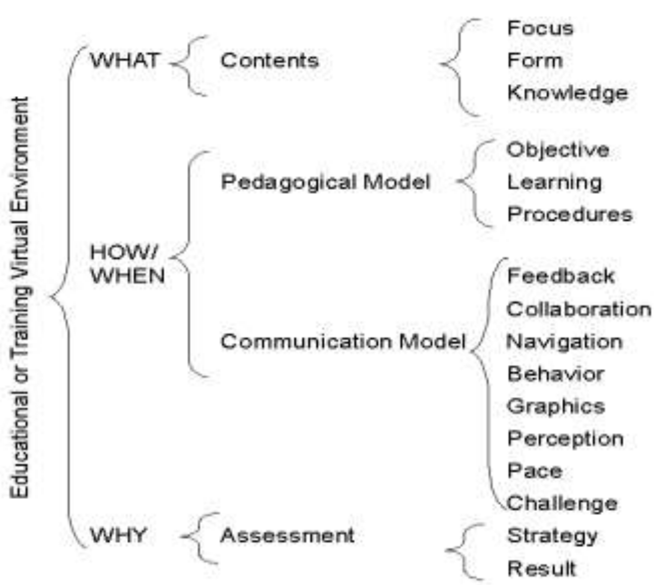

Fig. 1. Characterization of EVE and TVE.

The categories are, respectively (see Fig. 1): Content; Pedagogical Model; Communication Model, and; Assessment. In the Content category, "what" the TLVE is presenting to the apprentice is characterized more clearly. The Pedagogical Model and Communication Model categories emphasize "how" and "when" the TLVE deals with pedagogical and communication questionings. The Assessment category infers "why" the environment exists as an educational tool.

All the categories of features will be detailed and the settings that will be presented reflect what is most commonly found in the case of the respective type of TLVE.

2.1 Contents

Regarding the **focus**, the EVE has the use of abstractions as an important factor and also value comprehension [34]. Contrarily, the TVE focus mainly on the use of instructions and operations for the acquisition of skills.

As for the **form** of the contents that are presented to the apprentice, a TVE normally follows the "learn by watching" format ([19], where learning is performed through observation) or *"learn by doing"* ([19], where learning is performed through the execution of procedures/practices). On the other hand, an EVE is governed by mental processes through the application of techniques such as *"learn by comparing"* (through definitions/comparisons) and *"learn by thinking"* (through pondering on theories and concepts).

As for the **knowledge** present in the content, it is observed that most EVEs are focused on formal content and curricula. Whereas most TVEs deals with contents related to industrial and operational experiences.

2.2 Pedagogical Model

In EVEs, the pedagogical **objective** is the understanding and perception of values and perspectives while in TVEs the objective is the acquisition of specific skills and dexterity for technical training.

It was observed that the promotion of **learning** in EVEs is obtained through the mental models construction and decision-making, normally associated to Constructivism [30] or Socio-Interactionism [14]. TVEs are focused on actions and technical procedures which are usually coupled with Instructionist and Behaviorist approaches [20].

EVEs use non-exhaustive (varied) pedagogical **procedures** through explanation and visualizations [27]. And TVEs use repetitive procedures, with information/data given by commands and orders.

2.3 Communication Model

In the communication process, an EVE presents a comprehensive and discursive **feedback**. However, TVEs use a specific and direct feedback (for instance: scores, training status, etc.) [13].

Regarding the **collaboration,** the EVE it is expected to be multiuser and to provide more interactions and negotiations among apprentices. TVEs are usually single-user, because the acquisition of the training goals (normally physical and motor skills) should be acquired through individual discipline, although in some cases it may also require experience exchange with other apprentices.

On the **navigation**, it was observed that for most EVEs the apprentice freely explores the environment, leading to an unrestricted communication regarding her/his movements around the environment [27]. In the TVE there are predefined approaches (direction and orientation) because the apprentice needs to respect a sequence of steps.

The **behavior** of specific objects is a fundamental element in the communication model of the TLVE with the apprentice. In EVEs, approximated behaviors of the real thing suffice in several situations but need to cover a wide range of situations for variety sake. The TVE give emphasis to a detailed behavior of some specific object, in search for fidelity.

Regarding the **graphics**, it was observed that EVEs normally use mockery objects, because it is not necessary to visualize the target object with high visual accuracy to understand it [17]. And in the TVE, it is important for the training that objects are represented with realism, once the details are of great importance for the acquisition of specific skills [17].

In EVEs the greater number of human senses are preferred for the **perception** of the content, which helps the communication to become more meaningful, engaging and therefore better. In the TVE, there is a tendency to concentrate efforts in a minimum set of senses, but with a more faithful representation. This tendency reflects the kinesthetic and/or visual/motor coordination, since the communication is established according to the desired dexterity.

Regarding the **pace** of communication between the TLVE and the apprentice, it was observed that an EVE allows the control of the communication progress because it aims at efficiency of the learning process. And, a TVE presents the events and situations simulated in real time, without the apprentice being able to freeze or interrupt the communication, which emphasizes the effectiveness in the performance of tasks, because the decisions must occur at the right time.

In EVEs the computational **challenge** has been the learning model, because in these environments object models and behaviors are simpler. And, in TVE the computational challenge resides fundamentally in the modeling of the target phenomenon. Clarity over the challenges highlights the attention that must be paid to the communication metaphor. It is expected that what is more difficult to model would be more difficult to communicate.

2.4 Assessment

Regarding the assessment **strategy**, it has been noticed that EVE focus on a continuous evaluation of the apprentice or, level by level judgment allowing a formative assessment and mainly evaluating mental processes. In TVEs a definitive and final assessment is more commonly used, mainly related to manual processes, that is, whether the task was successfully performed, closer to a summative assessment.

As a **result** of the leaning process an EVE seeks the apprentice ́s understanding of concepts and embedding of values, and TVE seeks more concrete results, mainly related to conditioning (action) [23].

III. VR IN TRAINING

The previous section proved that EVE and TVE have some very distinct features. The areas of application of both are unlimited but, a closer and more immediate relation of TVEs with the productive sector is clear. Here, a special eye has been laid on TVEs aimed at assembly/disassembly training for maintenance because it has been stated [33] that VR systems increase efficiency and the ability to perform maintenance, operational tasks and service in the technical domain by: improving of the training mechanism due to 3D interactivity; increasing in the technical staff performance by providing a tool according to their demands; an interactive visual reference for maintenance tasks or operation; costs savings and avoidance of unnecessary efforts by providing training independently of time and place in a virtual machine rather than a real one; reducing the risks of defective maintenance actions and operations by allowing an interactive 3D version of the task; providing a better knowledge transfer inside the company through the implementation of a self-learning concept and; increasing operators safety, especially in the initial phases of training where it can be done in a virtual machine instead of a real one.

Through VR it is possible to have a training procedure where the apprentice repeats his/her activities several times, analyzing and improving her/his results; this factor builds up a sound knowledge base, often better when compared to a conventional system. From the scalability point of view, a virtual training system can reach a greater number of users in a shorter time [10]. Computer training, especially with VR, offers access to several advantages not covered in traditional training, because it facilitates the standardization and may provide distance learning contemplating real environment faithfully [37]. Trainees ́ skills retention is greater with the use of VR if compared to traditional methods, especially after a longer period of time [38].

It was observed that TVEs are more detailed in the literature than EVEs, which allows the deepening in its specific characteristics. A survey about TVEs aimed at training maintenance involving assembly/disassembly, identified a varied set of functional elements in the systems. These elements provide an evolutionary strategy for the use of TVEs. The coherent configuration between the different functional elements leads to the identification of recurrent patterns in TVE applications. These patterns are here called “training modes”.

IV. TRAINING MODES ON ASSEMBLY TVEs

It is not unusual to find that a TVE to present itself monolithically on a single mode of training and few are the systems that present more than one training mode. This fact does not mean that they present the training process as one big procedure. Rather, they all imply some sort of evolutionary approach within. Altogether with the difficulty of considering characteristics for the selection of the proper training mode, it is possible to notice a lack of standardization on what a training mode should be.

At least 4 (four) training modes were identified in the literature for Training-oriented Virtual Environments: dialog, demonstrative, guided and exploratory modes. These modes are accessed accordingly to the apprentice's level of skills (in this case, of maintenance procedures). These training modes meet the “skills principles” defined by ([12] *apud* [6]): dialog and demonstrative modes identify basic procedures and object properties; guided mode contributes to skill acquisition regarding the sequence of actions, and; exploratory mode meets the need of developing the "activity flow" skill. The characteristics of each mode are described as follows:

In the **dialog mode** [36], also called "discovery mode" [5], conceptual and theoretical information, normally in a textual format (including *hyperlinks* if necessary [21]), is presented to the apprentice, This information is related to the procedural content that will be applied later in the simulated 3D environment and/or allows the apprentice to discover/learn the shape and the spatial relationship among objects of the scene [35]. This mode promotes a learning strategy called *"learn by knowing"*.

There are some authors [11] who defend a mode (or a stage) alternative to this (less textual and more graphical), in the form of an "ambiance" of the apprentice to the virtual 3D world. In this case the training object is placed in the context of a larger environment. Throughout the exploration of the content, the system might be continuously evaluating the apprentice (formative assessment) to better guide him or, simply to evaluate her/him at the end of the whole procedure (summative assessment).

In the **demonstrative mode** [36], or automatic or presentation mode [5], the textual information is present but in a more straightforward relation to the procedure itself and the textual *feedback* would be richer in additional information about the procedure. The interactivity is low, often limited to conducting the rhythm of animated sequences that show what to do. Also, interactivity can be called indirect since the apprentice often acts on buttons (and not on the targeted 3D object). 3D manipulation is most often absent and the navigation might present restrictions in order to prevent the apprentice of being lost in the Virtual Environment or yet, lose the focus and attention required [32]. This method of training complies with the learning strategy of *"learn by watching"* or *"teaching by showing"* [1]. In the end, the system might perform some kind of summative assessment about the content or, just make sure the apprentice visited all the important atoms of content before releasing him to the next mode.

In the **guided mode** [5], the TVE presents more concise texts or narrated instructions [1], usually in the form of straightforward commands of the (sub) tasks to be fulfilled. Thus, the TVE will guide the apprentice throughout the procedure. The visual and textual *feedback* is very similar to the previous mode, however with shorter and more technical information. The selection sometimes happens in an induced way by the system showing the apprentice which object to select [11,21,32] or, disabling the selection of incorrect objects. This mode seldom requires complex manipulations or placements by the apprentice but do require handling the object on the scene, although facilitated by (i) some indications of the desired manipulation trajectory (such as *Virtual Lines*, [1]) and/or (ii) attracting the object being handled to its trajectory/position (*SNAP*, [22,32]). The navigation is free through the Virtual Environment or restricted just a bit. This mode allows a learning strategy called "*learn by doing"* [31] and must implement a system of formative (continuous) assessment and focused in correcting any deficiencies in specific procedures.

In the **exploratory mode**, also called free mode [32,5], no textual information to guide the apprentice of the TVE are offered. The apprentice has to take the initiative of exploring the Virtual Environment and performing the (sub) tasks to be fulfilled. This involves the correct selection of objects that, in this mode, have to be manipulated (oriented and/or placed) in a coherent way and without any help by the system. The feedback is basically visual, but may include some cues on correct actions, mainly throughout the task execution as well as non-obvious technical feedbacks. Mistakes are often punished or emphatically highlighted. The navigation is totally free in order to prevent the apprentice of noticing any kind of conduction/induction by the system. For the manipulation, there is no indication of trajectories or objects to be selected. This mode might be used also as a certifying module since it can implement both formative as well as summative assessment. The latter may lead to sound indication of good understanding of the whole targeted maintenance procedure realizing what can be called as the "*learn by assessment*" strategy.

V. VIRTUAL GENERATOR UNIT (VGU)

A TVE system for the maintenance of a Hydroelectric Energy Unit (HEU) using a desktop VR system is presented as a show case for the training modes defined at the previous section. The training process for assembling and disassembling HEU equipments [9] directly affects the energy generation quality and the level of operational risk. The HEU is a continuous production process where the hydraulic energy is converted into mechanical energy, and finally into electrical energy. The HEU is composed of three main sections: tubing, turbine and generator, as shown in Fig. 2.

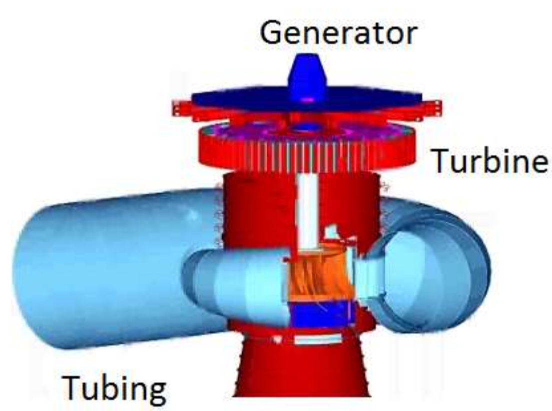

Fig. 2. Hydroelectric Energy Unit [9].（Color Plate 8）

HEU assembling and disassembling procedures meet the main requirements for virtual training [5,6,32,33]. The TVE that has been implemented is called VGU (Virtual Generator Unit) which corresponds to the sub-units of maintenance procedure training for all 3 HEU sections.

For maintenance training in a HEU to be satisfactory it is necessary that the training reaches the "enabled stage" [6] because it is not enough to have a superficial knowledge of parts´properties that make up the HEU section. It is necessary to know the assembly and disassembly instructions contained in manuals, that the trainee get acquainted with assembly sequences and also that her/his skills become in compliance with maintenance activities standards.

For the VGU implementation, a TLE was developed based on *Desktop* VR techniques with two main sub-systems:

- The first, the **educational sub-system**, implements "dialog" and "demonstrative mode" (which have been presented elsewhere [28][29]), and;
- The second, the **maintenance sub-system**, implements guided and exploratory modes explained earlier and which is the focus of this paper.

Fig. 3 shows VGU system´s architecture diagram composed of the training modules (educational and maintenance), interface module, loading module and user module. HEU parts are modeled using CAD software, organized in a hierarchical scene graph and documents in the XML (*eXtensible* Markup *Language*) format as database.

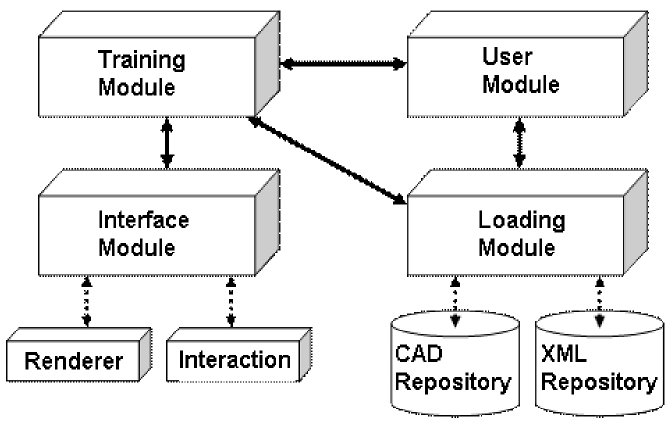

Fig. 3. VGU system architecture.

The main system module is the training one that manages all activities of the other modules, acting as the intermediary for the system's data exchange. The training module implements the rules for assembly planning, performs the sequences of assembly and disassembly and, assesses the trainees' performance regarding the procedures.

The loading module receives the training module requests to allocate memory for the CAD parts using 3D *Loaders*. This same module also loads the user and parts files that are both stored in XML files. The user file contains: user name, password, assessments, and task status. The parts files describe data such as: part´s geometrical data, part name, physical data, and positioning in the environment, among others.

The user module is responsible for the management of the data concerning the trainee, registering personal information such as name and password, and also assessment information from the training module, such as trainee performance and the conclusion status of the maintenance procedures.

Finally, the interface module promotes the interaction between the system and the trainee through two sub-modules, the "renderer sub-module", responsible for displaying the 3D virtual scene composed of HEU parts, and the "interaction sub-module", responsible for capturing user inputs, either by mouse or keyboard, and answering by textual feedback and/or in the virtual environment.

VI. THE MAINTENANCE SUB-SYSTEM

The VGU TVE allows the trainee to perform the maintenance procedures virtually, conducting HEU parts and equipments dismantling and assembling operations, which comply to operation and maintenance manuals for the turbine, generators and, embedded parts [3,24,25].

Fig. 4 shows the VGU interface which is divided in four areas: information about the parts tree and the training, at the top left; action buttons, at the leftmost side; the 3D virtual environment, at the center of the screen, and; a textual information feedback area, at the bottom.

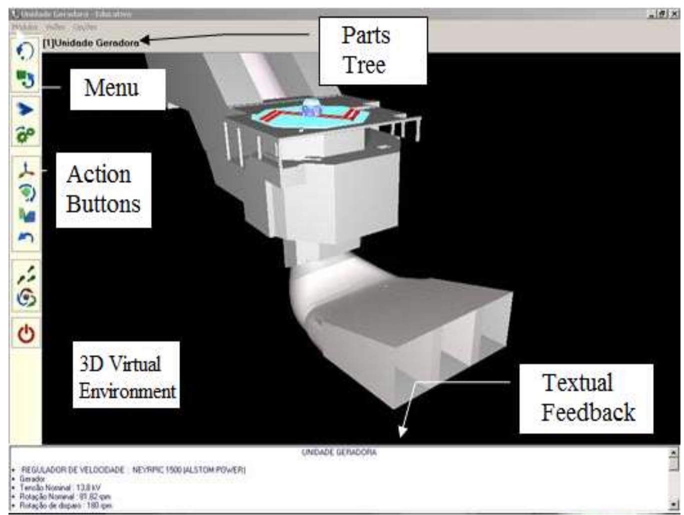

Fig. 4. VGU interface.

In the virtual environment, the trainee interacts directly with displayed objects using *picking* operation to obtain information, dismantle them and go down the levels of the parts tree. The trainee can also select other types of interactions through the action buttons and perform them on the objects or group of objects displayed.

The action buttons allow the selection of the desired interaction on the objects displayed in the virtual environment. The action buttons are divided in three groups:

- Selection buttons, allow the user to control the animations, go up and down onto the levels of the parts hierarchy, undo modifications and, redrawn the VGU in its initial position;
- Manipulation buttons, are used to rotate, move or make transparent one or more parts;
- Navigation buttons that allow the change of the observer's position to specific points of interest in the current training and, other observer´s repositioning in the virtual environment.

The bottom part of the screen displays textual feedback information which is synchronized with the actions in the virtual environment. This information varies accordingly to the type of training, and the trainee's degree of knowledge.

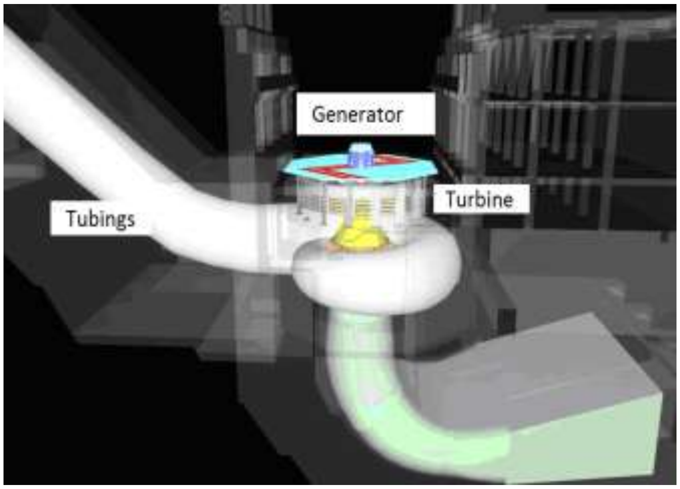

Fig. 5. Internal view of the HEU.（Color Plate 9）

The VGU tool meets the three main requirements for a *desktop* VR system to be suitable for maintenance training (these requirements are presented in [21]):

- Visualization: the system offers the trainees: (*i*) a general view of the maintenance environment so trainees can understand the assembly and disassembly process of a specific object in it; (*ii*) a detailed view of object ́s internals, to allow the understanding of its structure and the spatial relationship among objects (Fig. 6 shows HEU internal sections, using a transparency tool to de-emphasize the surrounding objects);
- Interactivity: the system offers the trainee the ability to interactively select the desired training as well as the visualization of the virtual assembly and disassembly sequence. The mouse pointer is used to select and handle the parts through indicative arrows, to move them in the X, Y and Z axes (as shown in Fig. 6a). The keyboard can be used for navigating in the TVE (as show in Fig. 6b).

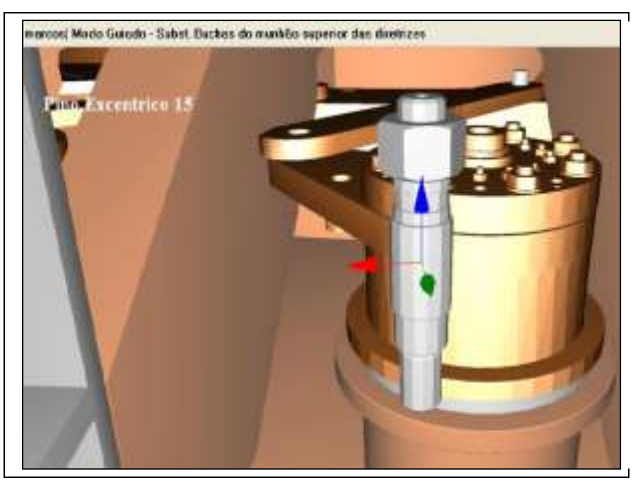

Fig. 6a. Selecting and handling the parts.（Color Plate 2）

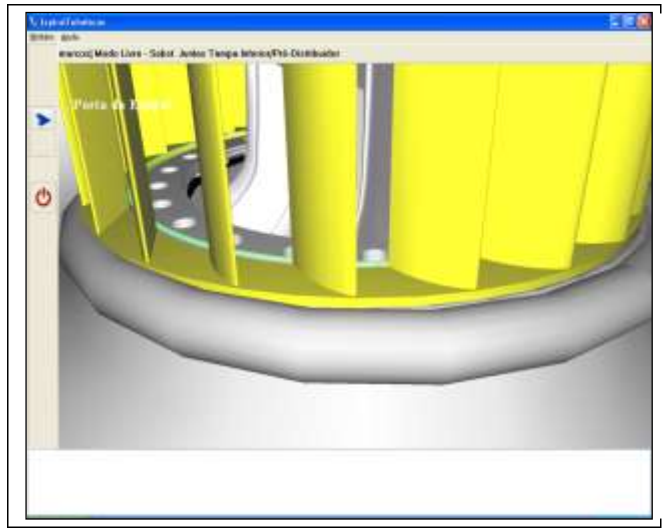

Fig. 6b. Navigation in the maintenance environment.

Fig. 7a. Real turbine rotor part.

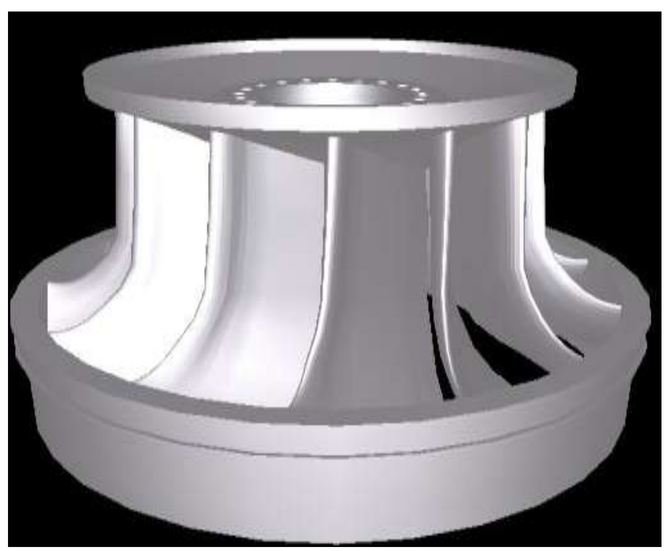

Fig. 7b. Virtual turbine rotor part.

Following the idea of step-by-step learning (previously presented in section 4), the maintenance sub-system implements three of the training modes, as it will be detailed following.

A. Automatic Training Mode

This mode is equivalent to the “demonstrative” training mode where the animation of the maintenance procedures is performed automatically as an initial guidance for the trainee. Depending on the type of animation chosen by the trainee, the respective automatic animation is performed and the procedure instructions are displayed in the feedback text area accordingly. The interaction with the virtual environment in this mode is kept at the minimum.

The maintenance procedure develops through an animation that shows the assembly and disassembly movements of the part, with the pace being controlled by the trainee. This training mode aims to present the parts that are involved in the maintenance, demonstrate the correct placement of the technician inside the HEU structure and the correct sequence in which the parts should be handled, as well as all the information required for a safe and complete procedure.

Fig. 8 depicts a sequence of animation for the bushing replacement. Every step of the animation is user controlled by “animation buttons” shown at the top left side of the interface.

Fig. 8a shows the beginning of the disassembly procedure animation. At the bottom part, in the textual information feedback area, the system asks the user to click the Animation Button to begin the procedures, and then the image at the center of the screen displays the removal of the eccentric pin (see the arrow) and the group A of screws. Fig. 8b shows the removal of the group B of screws (as pointed by the arrow) and, Figs. 8c and 8d show, the removal of the handle axis screw and its cover, respectively. Fig. 8e shows the removal of the rupture pin and the rod, and finally, Fig. 8f shows the removal of the (supposedly faulty) bushing. For the assembly procedure, the animation covers the inverse sequence, that is, starts by putting the new bushing and ends repositioning the eccentric pin.

B. Guided Training Mode

In the guided training mode, the system leads the user through the commands to perform the maintenance procedures. Unlike the automatic mode, in this one the trainee has to effectively perform the maintenance tasks using the *mouse* by selecting and moving appropriate parts.

When a part of the targeted maintenance is selected, a message at the textual feedback area informs the name of the part in the 3D scene area, and simultaneously, instructions related to the part are displayed altogether with the step-by-step task procedures. One should notice that only context parts can be selected and this is typical feature of this kind of training mode.

When a part is handled in the correct sequence a positive message is displayed informing that the part was disassembled/assembled with success. To make virtual parts behave closer to those of the real world, collision detection is applied, in order to prevent the trainee from conducting a part to penetrate another.

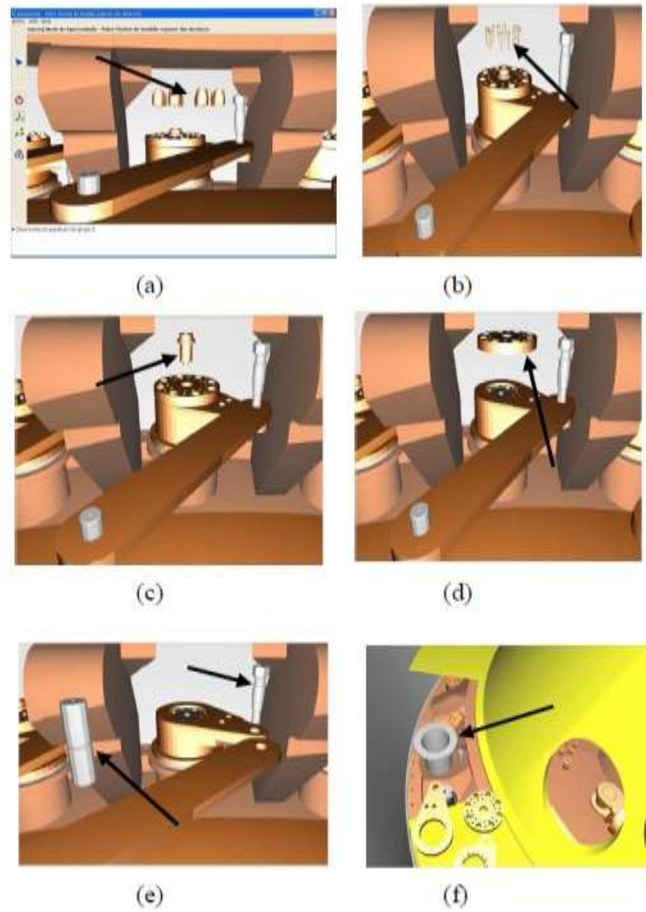

Fig. 8. Superior cap bushing maintenance operation: (a) removing group A of screws; (b) removing group B of screws; (c) removing handle axis screw; (d) removing handle cover; (e) removing rupture pin and rod, and; (f) removal of the bushing.

Fig. 9 shows an example of a maintenance procedure in the guided training mode (note the instruction given in the textual feedback area).

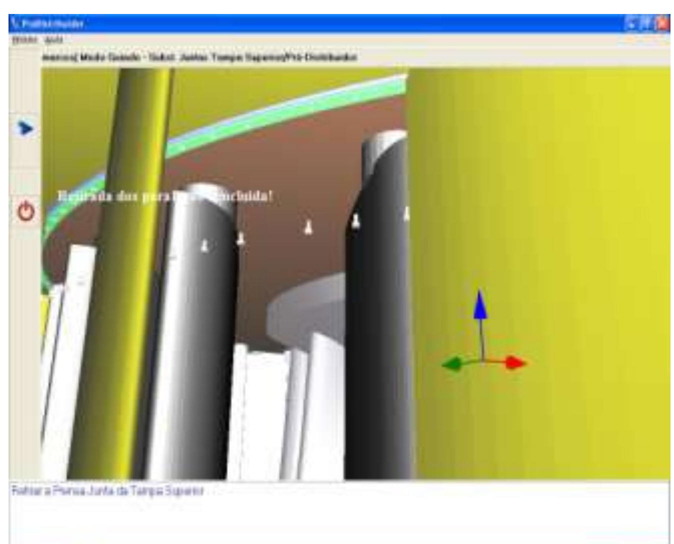

Fig. 9. Maintenance of the inferior cover joint of the pre-distributor.

（Color Plate 10）

C. *Exploratory Training Mode*

When starting this mode, the apprentice should be already well acquainted with the assembly and disassembly procedures, and from this moment on, the trainee's knowledge will be assessed by performing tasks without any help from the system. At the end of each correctly executed step the system displays a message in the virtual environment to indicate that the task was completed successfully.

No information about the maintenance procedure is shown in the textual feedback area but only messages related to the correct or incorrect selection of parts. Fig. 10 shows the same maintenance procedure as in Fig. 9 but in the next mode of training and in the next step (i.e., during joint removal, as indicated by the black arrow) and it can be seen that no guidance is given at the textual feedback area at the bottom of VGU.

At the end of the exploratory mode the system informs if the training mode was concluded successfully and thus, the trainee is able to learn another procedure, once the trainee have went through all the training modes related to the current procedure.

An assessment report is also displayed at the textual feedback area after successfully finishing the “exploratory mode”. The report displays the mode being trained (1-Automatic Mode, 2-Guided Mode and 3-Exploratory Mode); the evaluated training procedure (for instance, it could be a “substitution of the superior cover joint” or the “substitution of the inferior cover joint”, among others), and; the percentage of correct moves during the maintenance procedure.

In case the training was finished without any mistakes, the training system enables a button to advance to the next maintenance procedure, or in case the trainee wants to recap the task, the “restart” button is also enabled.

VII. CONCLUSION

Although many authors state the educational or training emphasis of their Virtual Environments the common ground to differentiate these systems are not so widespread. Therefore, mistakes happen either at the conceptual level (in which even the incorrect use of the terms “education” and “training” as synonyms occurs) as well as in new projects development (where the technological requirements of each emphasis are not taken into account). Thus, it is important to define the characteristics of these emphases. The correct differentiation allows objectivity on new projects regarding the desired niche and better use of the technological resources.

This paper presented a conceptual framework of features that help differentiate education-oriented from training-oriented resources in 3D Virtual Environment. Features related to content, communication model, pedagogical model and assessment were considered.

As for Training-oriented Virtual Environments (TVEs), specific resources were identified, called “training modes”, which should be carefully evaluated and considered in order for the TVE to fulfill its intended pedagogical objectives, making it clearly different from an Education-oriented Virtual Environment (EVE).

“Training modes” are conceptually coherent functionalities among themselves, are standardized, and inter-related in a cognitive logical way that can be incorporated in any TVE. It is believed that the most satisfactory implementation of TVEs happens when a diversified number of training modes are offered.

The use of all 4 (four) training modes allows for a system to accommodate the novice trainee, the most experienced and even the trainee who just wants a knowledge recycling.

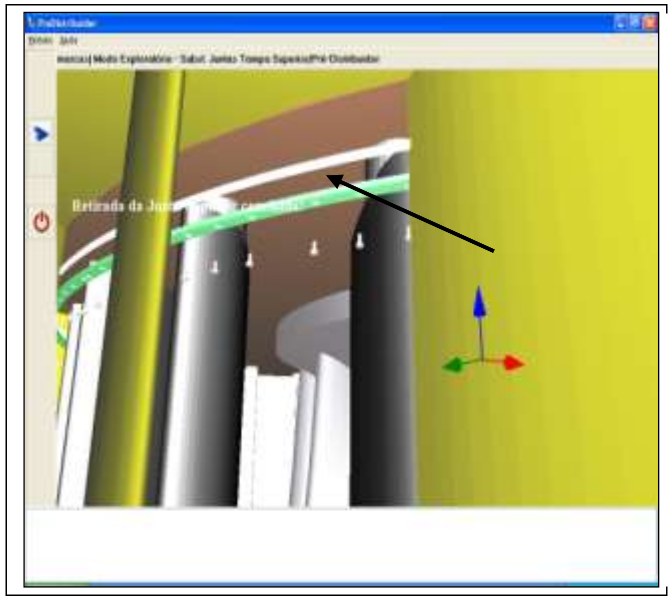

Fig. 10. Removal of the maintenance parts in the exploratory mode

This paper also presented the concept and prototype implementation of a virtual reality system aimed at training maintenance procedures of a Hydroelectric Energy Unit (HEU) that implements some of the previously specified training modes, which facilitated achieving its pedagogical objectives. This TVE is not limited to the visualization of 3D parts, as the objective of the work proposed by a similar system [15]. Rather, this TVE, called Virtual Generator Unit (VGU), offers a specific module for training and assessment, besides visualization.

As for the properties that help the virtual assembly and disassembly simulation processes [32], the VGU maintenance sub-system meets important features regarding the movement of virtual parts based on collision detection. The maintenance procedures are presented in a way that the trainee can gradually increase her/his involvement with the system, which is considered another requirement for this type of systems [5].

Therefore, the VGU TVE is in conformance with the proposed standardization, allowing specialized technicians to acquire knowledge of maintenance operations during training, which previously was limited to extensive documents reading and lectures.

The major contributions of this paper are the facts that with such standardized differentiation between TVEs and EVEs and the “training modes”, clear guidelines can be followed for better systems development and similar systems can now be compared between themselves.

ACKNOWLEDGMENT

This research has been made possible thanks to the financial support received from CNPq, UDESC, and Eletronorte S.A. and the authors would like to thank to Reginaldo de Matias for helping editing the final version.

REFERENCES

[1] N. Abe, J.Y. Zheng, K. Tanaka e H. Taki. "A training system using virtual machines for teaching assembling/disassembling operations to novices". *IEEE Int. Conf. On Systems, Man and Cybernetics*. Vol 3, pp 2096-2101, 1996.

[2] E. Arroyo, J. Arcos. "SRV: a virtual reality application to electrical substations operation training". *IEEE International Conference on Multimedia Computing and Systems*, Vol. 1, pp. 835-839, 1999.

[3] Assembly Manual for Embedded Part for the ALSTOM/ELETRONORTE. Ref. TUF-E-TUR-0006-MA-R5, 2001.

[4] A. Bierbaum. "VR Juggler: A Virtual Platform for Virtual Reality Application Development", Master Thesis, Iowa State University, 2000.

[5] E. Bluemel, et al. "Virtual environments for the training of maintenance and service tasks". *Winter Simulation Conference*, vol.2. The Fairmont New Orleans, pp. 2001-2007, 2003.

[6] A. C. Boud, et al. "Virtual Reality and Augmented Reality as a Training Tool for Assembly Tasks". *Proceedings International Conference on Information Visualization IV*, pp. 32 –36, 1999.

[7] I. Chiavenato. "Human Resources Training and Development: How to Improve Talents". 164 pgs. ISBN 8522444013. 4. ed. *São Paulo: Atlas, Brazil*, 1999. (In Portuguese).

[8] E. T. L. Corseuil, A. B. Raposo, et al."ENVIRON – Visualization of CAD Models In a Virtual Reality Environment". *Eurographics Symposium on Virtual Environments (EG-VE)*. pp. 79-82, 2004.

[9] W. P. E. Creager, J. D. Justin. "Hydroelectric Handbook". John Wiley & Sons, Inc. New York, 1962.

[10] D. C. Diehl. "Virtual Environment for the Manipulation of a Robotized Manufacturing Cell". Undergraduate Final Project on Computer Science) – Pontifícia Universidade Católica do Rio Grande do Sul. 61 pgs. 2004.

[11] R. Eastgate, "The Structured Development of Virtual Environments: Enhancing Functionality and Interactivity". PhD Thesis. University of Nottingham. 145 pgs. Sept 2001.

[12] P. M. Fitts. "The information capacity of the human motor system in controlling the amplitude of movement". *Journal of Experimental Psychology*, 47, pp 381-391, 1954.

[13] F. L. S. Garcia, et al. "Virtual Training Pit: A System for the Virtual Training of Aircraft Pilots". *V SBC Symposium on Virtual Reality, Fortaleza, Brazil*, pp. 1-9. 2002. (In Portuguese).

[14] M. Guimarães, et al. "The use the Valued Learning theory associated to Virtual Reality for the teaching of Electrical Circuitry". *ICECE – International Conference on Engineering and Computer Education*. pp. 830-834. São Paulo, Brazil. 2007. (In Portuguese).

[15] J. Guo, et al. "Visualization of a Hydro-Electric Generating Unit and Its Applications". *Systems, Man and Cybernetics, 2003 IEEE International Conference*, vol. 3, p. 2354-2359, 2003.

[16] C. R. Hall, C.D. Horwitz, "Virtual Reality for Training: Evaluating Retention of Procedural Knowledge". *International Journal of Virtual Reality*, 5(1):1-9, 2001.

[17] M. S. Hounsell, et al. "Scoring Strategies for Instructionist-Driven Education-Oriented Virtual Environments". *Global Congress on Engineering and Technology Education*, pp. 499-503. Bertioga, SP,Brazil, 2005.

[18] S. Jayaram, Y. Wang, U. Jayaram. "A virtual assembly design environment". *Proceedings of IEEE Conference on Virtual Reality*, pp. 172-179, 1999.

[19] Q. Jin, Y. Yano, "Design issues and experiences from having lessons in text-based social virtual reality environments. Systems, Man, and Cybernetics". *IEEE International Conference on. Orlando, FL, USA.* ISBN: 0-7803-4053-1. v.2. pp.1418-1423. Oct, 1997.

[20] W. Laaser, et al. Handbook for designing and writing distance education materials. Brasília, Editora Universidade de Brasília. Portuguese Edition. 1997,

[21] J. R. Li, L. P. Khoo, S. B. Tor. "Desktop virtual reality for maintenance training: an object oriented prototype system (V-REALISM)". *Computers in Industry*, 52(2):109-125, 2003.

[22] F. Lin, et al. "Developing virtual environments for industrial training". *Information Sciences - Informatics and Computer Science*: An International Journal, 140(1):153-170, 2002.

[23] R. F. Mager. "Preparing Instructional Objectives: a critical tool in the development of effective instruction". 3rd.ed. *Atlanta:Center for Effective Performance*, 1997.

[24] Maintenance and Operational Manual of the Generator ALSTOM/ELETRONORTE. TUF-E-TUR-0010, 2002.

[25] Maintenance and Operational Manual of the Turbine-ALSTOM/ELETRONORTE. TUF-E-TUR-0010, 2002.

[26] B. S. Meiguins, et al. "Virtual Reality applied to teaching and learning of Kinematics". *III-International Conference on Engineering and Computer Education, ICECE*. pp. 16-19. 2003. (In Portuguese).

[27] P. T. Nakamoto, et al. "Use of Conceptual Maps for the Construction of Learning Virtual Environment". *Annals of XXV Congresso da Sociedade Brasileira de Computação*. Porto Alegre - RS: pp. 1847-1860. 2005. (In Portuguese).

[28] A. Pamplona, M. F. Ribeiro, M. Sousa, P. Barata, M. Nascimento, M. Hounsell. "A Virtual Reality System for Maintenance Training and Study of a Hydroelectric Energy Unit". *XII Congreso Argentino de Ciencias de la Computación, CACIC*, 2006. (In Portuguese).

[29] A. Pamplona, M. F. Ribeiro, M. Sousa, P. Barata, M. Nascimento, M. Hounsell. "A Virtual Reality System for Hydroelectric Generating Unit Maintenance Training and Understanding" *ISCA 19th International Conference on Computer Applications in Industry and Engineering (CAINE)*. USA, 2006.

[30] A. Pasqualotti, C. M. D. S. Freitas. "VRML environment for the teaching and learning of maths: conceptual model and a prototype". *3rd WRV - Workshop on Virtual Reality: SBC - Soc. Brasileira da Computação, Gramado - RS - Brasil*. pp. 65-76. 2000. (In Portuguese).

[31] M. Roussou. Learn by doing and Learning through play: an exploration of interactivity in Virtual environments for children. *Computer in Entertainment*, 2:10-23 (2004).

[32] A. Sá, G. Zachmann. "Virtual reality as a tool for verification of assembly and maintenance processes". *Computer & Graphics Journal*, 23(3):389-403, 1999.

[33] M. Schenk, E. Blumel, et al. "Technology Enhanced Training at Workplace: A Virtual Reality Based Training System for the Technical Domain".*1st International Conference on Business and E-Learning Proceedings*, ISBN 9957-8585-0-5, p. 57-62, 2005.

[34] J. Seo, e G. J. Kim. "Design for presence: a structured approach to virtual reality system design". *Presence: Teleoperators and Virtual Environments*, 11(4):378- 403, August 2002.

[35] R. Suzuki Jr, et al. "On the Introduction of Text in Virtual Environments". *VIII Symposium on Virtual Reality, Porto Alegre - RS - Brazil*, pp. 1-12. 2006. (In Portuguese).

[36] E. Tam, F. Badra, et al. "A Web-based virtual environment for operator training [for power systems]". *IEEE Transactions on Power Systems*, 14(3):802-808, 1999.

[37] J. Vora, S. Nair, A. K. Gramopadhye, A. T. Duchowski, B. J. Melloy, B. Kanki, "Using virtual reality technology for aircraft visual inspection training: presence and comparison studies". *Applied Ergonomics 33*. pp. 599-570. 2002.

[38] D. Waller and J. Miller,"A desktop virtual environment trainer provides superior retention of a spatial assembly skill". *Proceedings of the Conference on CHI 98 summary: human factors in computing systems*, p. 339-342, 1998.

[39] Q. Wang, J. Li, "A desktop VR prototype for industrial training applications". *Virtual Reality*, 7(3-4):187-197, Springer, 2004.

[40] P. Ye, Banerjee, A Banerjee., et al. "A comparative study of assembly planning in traditional and virtual environments". *IEEE Transactions on System, Man, and Cybernetics-Part C: Applications and Reviews*, 29(4):546-555, 1999.

Marcelo da Silva Hounsell received his degree in Electrical Engineering from Federal University of Pará (UFPa, Brazil) in 1989, his M.Eng. in Electrical Engineering from State University of Campinas (UNICAMP) - Brazil in 1992, and his PhD in Manufacturing Engineering from Loughborough University of Technology – UK in 1998. He is a full time Associate Professor at State University of Santa Catarina (UDESC, Brazil) and a member of the Brazilian Computer Society (SBC). He is the leader of the LARVA (LAboratory for Research on Visual Applications) research group and laboratory at UDESC. His research interests includes Virtual Reality, Interactive Computer Graphics, Computer Animation, Feature-based Modeling and, Computer Aided Design.

Edgar Luis da Silva received his bachelor degree in Computer Science from State University of Santa Catarina (UDESC, Brazil) in 2009. He is a former member of the LARVA (LAboratory for Research on Visual Applications) research group and laboratory at UDESC where he has received a scholarship grant to participate in many research projects. He is a qualified VRML and Java programmer.

Manoel Ribeiro Filho received his degree in Electrical Engineering from Federal University of Pará (UFPa, Brazil) in 1979, his MEng and PhD in Electrical Engineering from UFPa in 1991 and 2002. He is a full time Associate Professor at Federal University of Pará. He has a background in Computer Graphics and Games focused on themes that include: Industry Use of Virtual Reality for Training; Informatics in Education; Educational Computer Games and; Virtual Laboratories.

Marcos Paulo Alves de Sousa received his bachelor degree in Computer Science from Federal University of Pará (UFPa, Brazil) in 2002, his Master´s degree in Electrical Engineering from UFPa in 2004, and his PhD from UFPa in 2009. He has been interested in the use of Virtual Reality to aid training and planning complex maintenance tasks.