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DESIGNING THE 3D GUI OF A VIRTUAL REALITY TOOL FOR TEACHING DESCRIPTIVE GEOMETRY

Rodrigo D. SEABRA and Eduardo T. SANTOS
Escola Politécnica, University of São Paulo, Brazil

ABSTRACT: Today, the design of a suitable graphical user interface (GUI) is recognized by designers, researchers and developers as a vital part of the development of software and even of hardware. It must take into consideration both the application context and the interaction tasks to be carried out by the target users. Most current computer users are getting used to a standard set of user interface components and adapting to common interaction techniques for performing their tasks. In spite of this adjustment, it is known that generic interface components like buttons and menus are not always appropriate for use in non-traditional computer environments and in applications with modern interaction techniques, especially Virtual Reality (VR). In VR environments, the user manipulates and interacts with objects, in any orientation, positioned in space. Interaction in 3D space has been explored in several areas and, among them, for teaching Geometry. Some interesting results on learning and user satisfaction have been reported. Descriptive Geometry, although based on a planar (2D) representation, can also benefit from such kind of interface as it concerns 3D space. For this reason, VR tools could improve teaching of Descriptive Geometry in engineering and other courses when used as an enhanced technique for visualization and interaction. This paper presents the design of a new 3D user interface intended to be integrated in the traditional descriptive geometry class setting. The device selection, requirements and specification of interface behavior and components are covered here. The proposed system, still under development, will be a VR tool aiming to improve the spatial visualization abilities of engineering students, promoting comprehension of complex spatial geometric exercises, especially by low visualizers.

Keywords: 3D User Interface, Virtual Reality, Descriptive Geometry.

1. INTRODUCTION

Due to its importance for Engineering and other fields, Descriptive Geometry (DG) has being researched on several studies in the last decades [8, 10, 11, 13]. [4] defines DG as *"the branch of Geometry that studies the representation of three- dimensional objects on a plane, using systems based on the concept of projecting a point on a plane in order to reduce the three spatial dimensions to the two dimensions of the plane"*. [5] describes DG as *"the research and technology of producing graphic representations of three-dimensional objects and solving three-dimensional geometric problems using the graphic representation"*. Therefore, DG is a tool for representation and problem solving.

In the educational realm, DG has a third function: to develop student's spatial visualization abilities [12].

Despite its importance, Descriptive Geometry is considered a hard to learn topic by the many entering students in engineering courses who do not have properly developed spatial abilities. This deficiency makes it more difficult for them to understand the spatial configuration of geometrical elements in problems and to catch up with other students in class. This problem is made worse by the

fact that today there are less DG classes in university courses, and the students have to master the subject and develop their spatial skills in shorter time. This is a frustrating situation for many of these students.
Considering this scenario and the new computer technologies available for improving educational methods, some research has been conducted to develop spatial abilities using modern information technology tools [7, 14]. This paper presents a research in progress concerning that goal. Both the definition of requirements and the interface components of a virtual reality-based tool for supporting teaching of Descriptive Geometry are shown. This innovative software aims to make it easier for low spatial skilled engineering students to understand three-dimensional geometrical scenes, helping them to develop their spatial abilities.

2. 3D GRAPHICAL USER INTERFACES

The design of the user interface is acknowledged by developers, designers and researchers as a crucial phase on software and hardware development [2]. More than ever, today's computer users are familiarized with a standard set of interface components, including output devices like the monitor, interaction techniques like drag–and-drop, dropdown menus and interaction metaphors like direct manipulation. However, most of these interface components are not appropriate for using with nontraditional computer environments and modern interaction techniques, especially Virtual Reality (VR). In VR, user interacts with objects embedded in 3D space, in any orientation. In such environments, it is necessary to use new devices and interaction techniques and, possibly, new metaphors.
[3] states that the development process for 3D interfaces has not reached a mature stage yet and a standard methodology for designing and constructing spatial interfaces is lacking.
Several interaction techniques for 3D environments are reported on technical literature and human-related aspects have been investigated, but there is no consensus on how these results can be combined. As the space of possibilities of 3D interfaces is significantly larger than that of 2D interfaces, it is more difficult to design for them. Nowadays, designers have to deal with numerous input and output devices and, as available technologies are in constant development, innovations on interaction techniques are possible and, consequently, reevaluation of previous knowledge is needed.
"The communication process between the user and the system" is one way of describing human-computer interfacing. In this process, the user sends commands operating the interaction device which translates the user physical actions into an electronic format to the system. The system converts this information to a digital format which is processed and later interpreted and converted by the visualization device into visual stimulus to the user. The interface acts as a translator or mediator between the user and the system.
In general, interaction devices allow the user to move and manipulate objects in virtual world, connecting his actions with the scene elements in the simulated environment. Several VR devices for different purposes are available and it is important to define the most appropriate for the application at hand as they have a significant impact on the usability, a key aspect on educational applications.
The device selection must take into account not only the device capabilities but also the application itself because it is up to the software to adequately exploit the device features, mapping them to its functionalities.

2.1 Classification of Input Devices

[2] classified the physical input devices used for 3D interaction in several categories:

- *Desktop input devices*: keyboards, 2D mice, trackballs, pen-based tablets,

joysticks and 6-DOF (six degrees of freedom) desktop devices;
- *Tracking devices*: motion trackers, eye trackers and data gloves;
- *3D mice*;
- *Special purpose input devices*;
- *Direct human input devices*: speech, bioelectric and brain inputs.

The appropriate selection of input devices for a given application is a difficult task that can be helped by this and other classifications and taxonomies, as they allow the designer to discard devices in categories that do not fit the system's requirements, narrowing down the choices.

Usually, more than one device is responsible for input tasks in 3D applications because several specialized devices provide better mapping to interaction techniques than one or two generic ones [2].

2.2 Selection of Interaction Devices for 3D Interfaces

There are some key requirements a didactic tool like the one proposed in this work should obey, concerning input and output devices:
- *Input*: inexpensive, intuitive, support for 3D interaction and picking, text input (file operations, naming of primitives);
- *Output*: many users at the same time (classroom), inexpensive, depth perception (vital to this application, as it must aid spatial visualization);

Considering the need for text input and the universal availability of the keyboard, this was one of the devices preselected for the system input. Adopting the mouse for fulfilling the other input requirements was a tempting choice. However, some studies cited by [2] have shown that 3D devices (3 or more DOF) outperform the omnipresent 2D mouse in interaction speed, without loss of accuracy.

On the other hand, desktop-based devices provide more control and coordination than free moving 6-DOF devices [15], which perhaps will be a necessary feature for selecting small entities like points and thin lines in the system's interface.

The availability of a new, low cost, 6DOF desktop-based device made the decision easy, after all. 3Dconnexion's Space Navigator (Figure 1) was selected, together with the keyboard, as the system's input device.

Figure 1: Selected 6-DOF input device [1].

This US$50.00 device supports six degrees of freedom, outputting acceleration rates for translations in the direction of all three main axes as well for rotation about those same axes. Besides, it has two buttons on the sides of its base whose states can also be read by the device driver.

The output device was chosen from the start of the project: two multimedia projectors equipped with polarizing filters, a silver (light polarization preserving) screen and 45+ polarizing glasses. All these pieces together form a passive stereo output system, which is driven by a dual head graphics card on a PC computer. The audience is a 45-student classroom.

3. SYSTEM REQUIREMENTS

Requirements are the needs the computer system must fulfill and the constraints it must obey in order to offer the user the conditions and capabilities for solving a problem or accomplishing a goal [6]. The proper determination of requirements is needed for any computer system, whether VR-based or not.

The tool designed in this research is intended to be used by an instructor in the classroom.

Essentially, it allows the interactive construction of scenes with geometric entities representing exercises or concepts the DG instructor wants to show the students. The images will be presented in a projection screen and the students, wearing stereo glasses, will see them with depth perception.
Its requirements are: to enable…

- Environment navigation
  - arbitrary point of view;
  - isometric view;
  - orthogonal views.
- Construction of points
  - arbitrary;
  - on a line;
  - on a plane.
- Construction of lines
  - arbitrary;
  - by two points;
  - on a plane;
  - by its projections;
  - parallel to a plane or line;
  - perpendicular to a plane or line.
- Construction of planes
  - arbitrary;
  - by three points;
  - by two parallel or intersecting lines;
  - by a point and a line;
  - parallel to a plane or line;
  - perpendicular to a plane or line.
- Automatic generation of
  - projection of lines and points in projection planes;
  - intersection points between lines and between lines and planes;
  - intersection lines between planes.
- Definition of object's color, name, visibility and transparency;
- Object deletion;
- Object motion and rotation;
- File operations
  - new;
  - save;
  - load.

Creation of an interaction technique for a 3D interface, providing it with appropriate behaviors to realize the system requirements and, at the same time, with adequate mapping to the selected input and output devices was the major challenge of this development phase. Added to this, intuitiveness and simplicity were indispensable qualities of pedagogic tools one could not deviate from during design. Lessons learned from the development of the Risko 2D system [9] helped to devise appropriate solutions.
The proposed interface is described in next section.

4. DESCRIPTION OF INTERFACE

There are no conventional buttons or menus in the proposed interface. At first, only the two Mongean planes (horizontal and frontal projection planes) are seen on the screen, which acts as a window on an infinite workspace.
Interaction with the interface is done using the 6-DOF input device mentioned in section 2.2 and, in a few cases, with the keyboard. Output is done through a passive stereo projection which allows depth perception, making it easy to navigate and position objects in the virtual 3D space.
A state diagram of the interaction with the proposed interface is presented in Figure 2. A full description of components and operation of the interface are given in the next subsections.

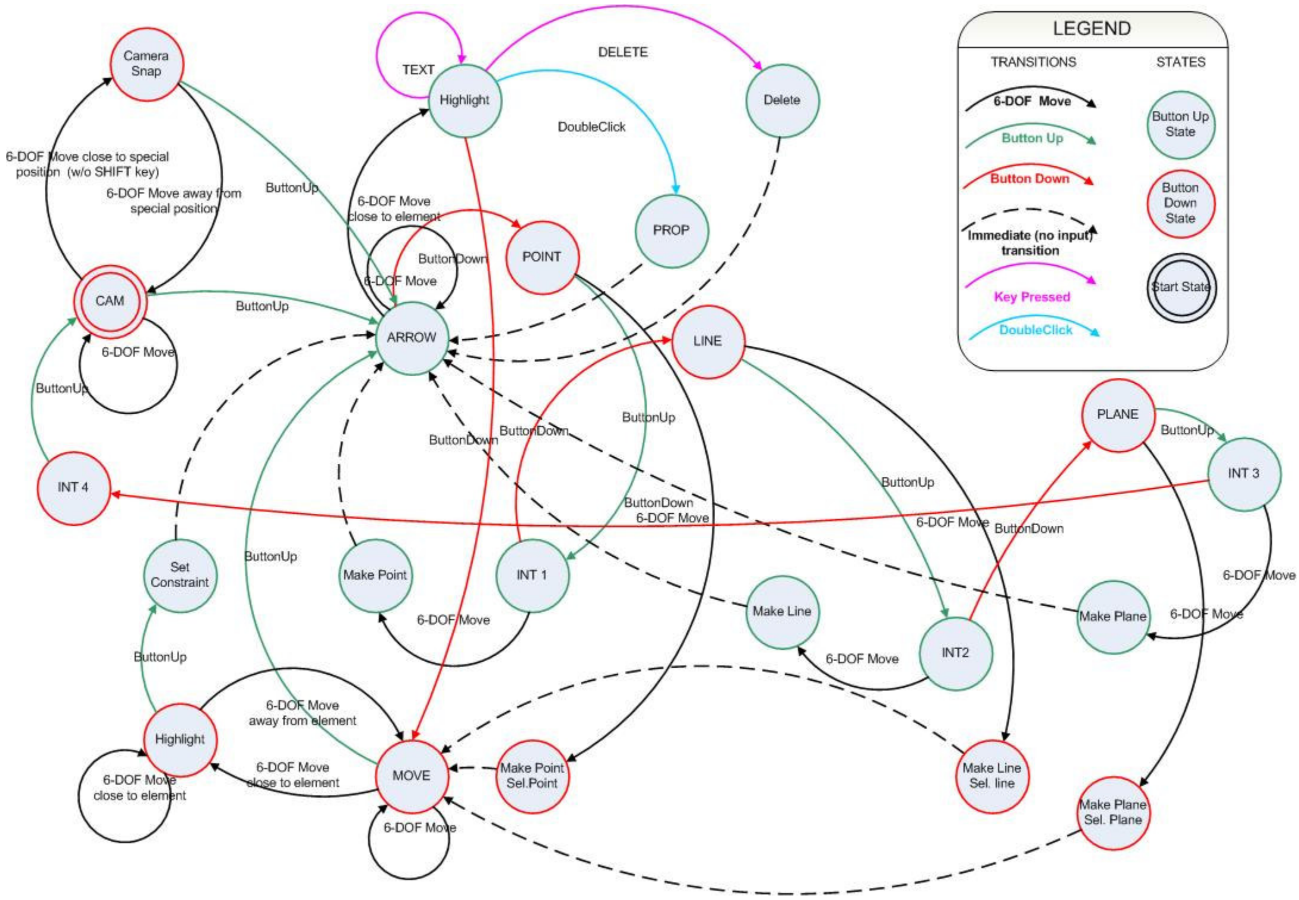

Figure 2: Interface state diagram (INTx = Internal states).

4.1 Workspace

The workspace represents the 3D space and is, therefore, potentially infinite. Initially, it only contains the frontal and horizontal projection planes (see Figure 3). Further elements are to be constructed by the user.

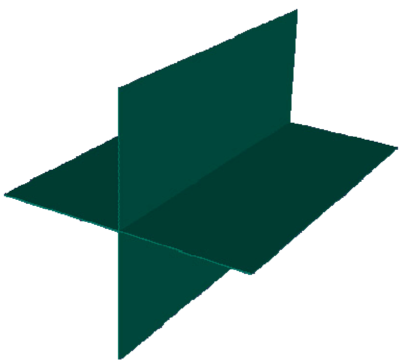

Figure 3: Projection planes in the workspace.

Operating the input device allows control of a "virtual camera" and navigation in the virtual space. The six degrees of freedom of the input device let the user both move the camera in all three main directions and rotate it around the three axes. The signal of rotations and moves are inversely mapped to the camera so that the user feels as if controlling not the movement of the camera, but of the whole space instead, the pivot point always at the coordinate system origin, in the ground line.

The output image of the workspace is generated according to a perspective projection, as can be readily seen in figure 3. This is because parallel projection is not useful for stereo viewing as two distinct images, one from each eye position, must be created.

4.2 Pointer

The pointer is represented in the workspace by a 3D arrow and is controlled by the 6-DOF device. It is used for dragging objects which, when selected, get linked to the movements of

the input device.
It can also be used by the instructor to call attention of the students to some element in the scene.

4.3 Primitives and snapping

The primitives in this system are points, lines and planes.
Points are represented by small spheres, lines are thin cylinders and planes are very shallow boxes. Figure 4 shows an example with all primitives.

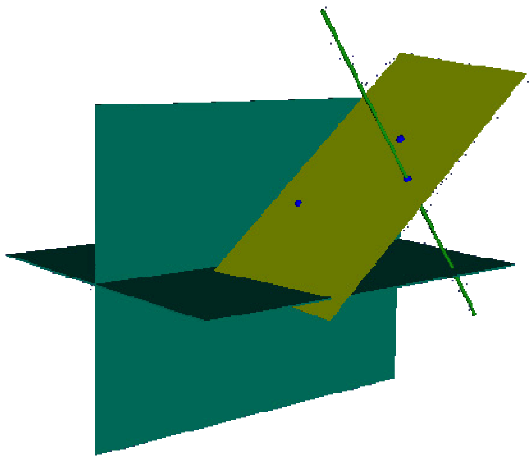

Figure 4: Points, line and planes.

When a primitive is dragged approaching another one, they may be highlighted indicating the opportunity to set a constraint or relationship between them. The kind of constraint depends on the relative position of one in relation to the other, and this position may be only approximate. The following relationships are possible:

- Point lying on line or plane;
- Line lying on plane or through a point;
- Plane through a point or line;
- Line parallel/perpendicular to line or plane;
- Plane parallel/perpendicular to line;

Figure 5 shows a highlighted line about to establish a perpendicular relationship with a plane. If the dragged primitive is released while it is highlighted, it will snap into precise position and set a constraint, afterwards moving together with its parent primitive whenever it is moved.
These constraints are not valid upward, i.e., a primitive is affected by translations or rotations on its parent (or grandparents), but moving a younger primitive does not affect older primitives it is related to.

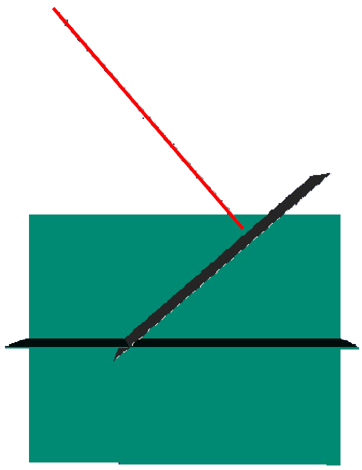

Figure 5: Perpendicular constraint.

4.4 Automatic Primitives

Intersection points and lines are automatically created when primitives intersect. Primitives created this way are represented with smaller dimensions than user constructed points and lines. Figure 6 shows an intersection point between two lines.

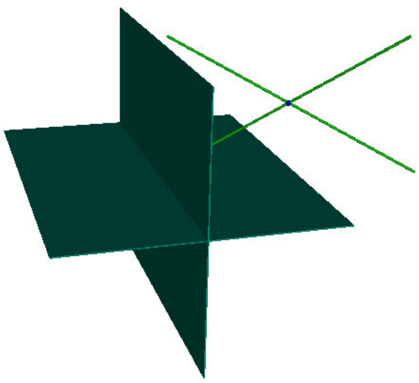

Figure 6: System-created intersection point.

The projection of points and lines in the projection planes as well as intersections of planes with them (traces) are also automatically created. However, they are only displayed, together with dashed projection lines, when the pointer approaches the primitive in space, so that visualization is not cluttered (Figure 7).

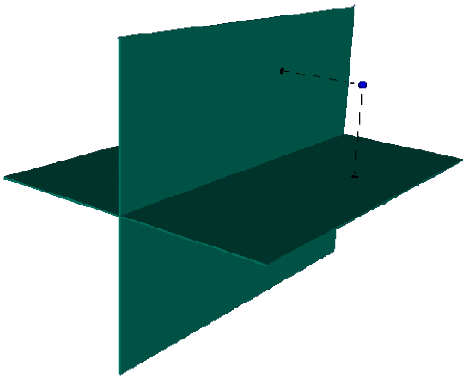

Figure 7: Projection of a point.

4.5 Interaction Modes

The interface has 5 main interaction modes: CAMERA, ARROW, PROPERTIES, POINT/LINE/PLANE and MOVE.

Mode transition is operated by the 6-DOF device's side button. The modes cycle in the sequence indicated on Figure 8.

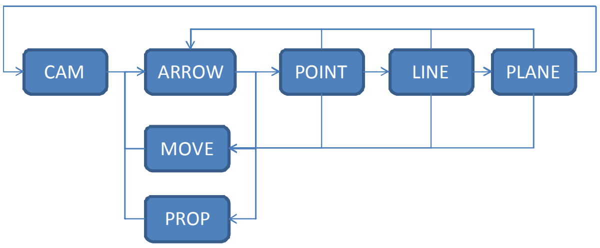

Figure 8: Interaction modes cycling.

The next sections detail the interaction in each of these modes. The state diagram on Figure 2 refers to these modes.

4.5.1 Camera Mode

This mode allows navigation in the virtual workspace. There is no pointer in the screen when in camera mode. It is the initial mode and navigation is performed on the 6 degrees of freedom using the input device.

When the viewing angle approaches a particular viewing position (isometric, frontal, horizontal or side view), the camera snaps into a precise angle, making it easy to view the workspace from those specific points of view. As central projection is used, these are only approximate positions (see Figures 9 and 10). Keeping the shift key pressed, avoids snapping.

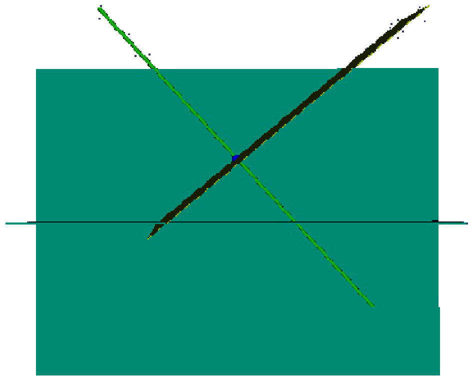

Figure 9: "Front" view.

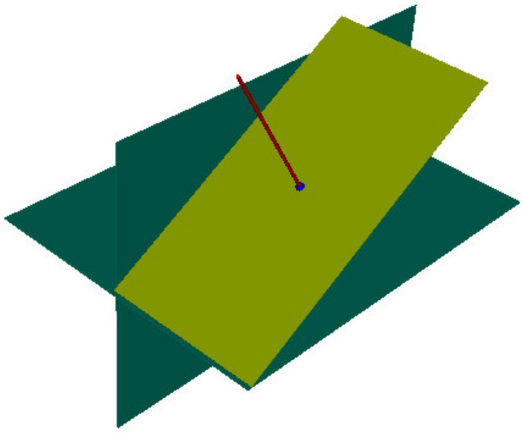

Figure 10: "Isometric" view.

4.5.2Arrow mode

The pointer (a 3D arrow) appears on the workspace and is controlled by the 6-DOF device, letting the instructor to call student's attention to a certain location. If the pointer approaches a primitive, it is highlighted and may be targeted for further operations. In this state, the selected primitive may be erased by pressing the DELETE key on the keyboard or may be named just by typing a name for it. A double click with the 6-DOF device button brings up the properties panel and the system enters the PROPERTIES MODE.

4.5.3 Properties mode

In this mode, the user can set the color, visibility and transparency of selected primitives, using a control panel. The exact form of this panel is yet to be defined.

4.5.4 Primitive mode

There are three submodes (POINT, LINE and PLANE) where each of the main primitives can be created and positioned. As mentioned before, the 6-DOF device's side button is used for changing interaction modes. When the button is pressed entering one of these modes, a primitive is created. Moving the 6-DOF device makes a transition to MOVE mode. Releasing and pressing the button again, before any movement, changes the state to the next mode. After the PLANE mode, the system returns to the CAMERA mode. Figure 11 shows the creation of a line.

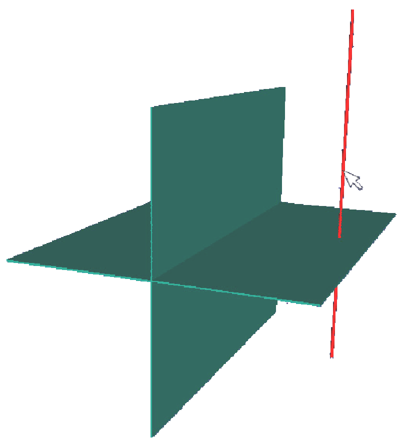

Figure 11: Creating a line.

4.5.5 Move mode

In the MOVE mode, the selected primitive follows the commands of the input device until its button is released. This allows the user to rotate and position the primitive as needed. When rotating, the pivot point is at the center of the visible part of the primitive.

4.6 File management

File management operations are made only upon startup. When system is initialized, a file panel is shown and the user has the opportunity to select an existing file or create a new one, by typing its name.

There is no need for an explicit "save" command, as all workspace modifications are immediately saved on the current file.

5. CONCLUSIONS

This paper presented the system requirements, device selection and interface components and methods of a VR-based educational tool for Descriptive Geometry teaching.

Its rationale is that if it makes easier for low visualizers to perceive spatial configurations, than it can help them to understand how problems are solved in space and push them forward to learn Descriptive Geometry techniques.

The proposed interface is intended to be very simple and intuitive, and to allow construction of points, lines and planes in a virtual workspace. Its input uses the keyboard and an inexpensive 6-DOF desktop device. The output is implemented as a passive stereo projection system.

A controlled experiment is planned for assessing the efficacy of this tool, both operating in stereoscopic mode and in monoscopic mode, so that the contribution of stereo projection can be evaluated.

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ABOUT THE AUTHORS

1. Rodrigo Duarte Seabra holds a B.S. in Computer Science and is a Ph.D. student in the Department of Civil Construction Engineering, Escola Politécnica, University of São Paulo, Brazil. His research interests are in Virtual Reality, Software Engineering, Educational Software and Graphics Education. He can be reached by e-mail: rodrigo.duarte@poli.usp.br, by phone: +55-11-3091-5438 or through postal address: Edifício de Eng. Civil / Cidade Universitária / 05508-900 São Paulo – SP / Brazil. Website: http://rodrigoduarte.pcc. usp.br

2. Eduardo Toledo Santos, Ph.D., is an Assistant Professor in the Department of Civil Construction Engineering, Escola Politécnica, University of São Paulo,

Brazil. His research interests are in Graphics and Distance Education, Virtual Reality and Applications of IT to Construction. He can be reached by e-mail: eduardo.toledo@poli.usp.br, by phone: +55-11-3091-5284 or through postal address: Edifício de Eng. Civil / Cidade Universitária / 05508-900 São Paulo – SP / Brazil. Website: http://toledo.pcc.usp.br