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Full Length Research Paper

Construction planning supported in 4D interactive virtual models

A. Z. Sampaio* and J. P. Santos

Department of Civil Engineering and Architecture Av. Technical University of Lisbon, Rovisco Pais 1049-001 Lisbon – Portugal.

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The construction of a building has been traditionally supported on the timeline schedules of the construction activities established in each case, and on technical drawings of the project. A prototype based on virtual reality (VR) technology with application to construction planning, was implemented. This interactive virtual model intends to present the project in a three-dimensional (3D) way, connected to construction planning schedule, resulting in a valuable asset in monitoring the development of the construction activity, based on the construction planning designed. The 4D application considers the time factor showing the 3D geometry of the distinct steps of the construction activity, according to the plan establish to the construction. The 4D model offers a detailed analysis of the construction project. Additionally, VR technology is used and presented as an innovative visual tool. It allows the visualization of different stages of the construction and the interaction with the construction activity. This application clearly shows the constructive process, avoiding inaccuracies and building errors, and so improving the communication between partners in the construction process. This tool is an important support in project conception and application.

Key words: Virtual reality, 4D models, construction planning.

INTRODUCTION

In construction management, technical drawings have had, throughout times, a crucial role in communication between the numerous partners in a project. Generally, drawings represent formal solutions, and often incompatibility mistakes are only detected in advance stadium, on site, with additional costs. In this field, 4D models, where the time factor is added to the three-dimensional (3D) model, promote the interaction between the geometric model and the construction activity planning, allowing immediate perception of the work evolution. With planning, correct evaluation and adequacy to intervenient needs, 4D models are a positive contribution decisions-maker when establishing planning strategies (Webb and Haupt, 2003). Moreover, virtual reality (VR) technology makes possible the interaction and the visualization of the construction work evolution, both immersive and interactively.

The main aim of a research project, now in progress at the Department of Civil Engineering of the Technical University of Lisbon, is to develop virtual models as tools to support decision-making in the planning of construction management and maintenance. A first prototype concerning the lighting system has already been completed (Sampaio et al., 2010). A second prototype concerning the maintenance of the closure of walls, both interior walls and façades, was also developed (Gomes, 2010). The present prototype was implemented, supported on VR technology, where the construction of a building and the related sequence of activities are used (Santos, 2010). Actually information technology namely 4D modeling (3D+time) and VR technics has been used in the construction activity and in education (Mohammed, 2007). At the Department of Civil Engineering of TU Lisbon, some didactic models were generated. The research project, presented in this paper, follows this previous work concerning education: Two 3D geometric models were created to help the rehabilitation of buildings activity (Sampaio et al., 2006); and three VR models were developed to support classes (construction of a wall, of a bridge and of a roof), of Technical Drawing, Construction and Bridge disciplines, concerning Civil Engineering educational field (Sampaio et al., 2010). The didactic VR

*Corresponding author. E-mail: zita@civil.ist.utl.pt.

models are usually presented in both face-to-face classes and in a e-learning platform.

CONSTRUCTION PLANNING

Construction management can be defined as "the planning, co-ordination and control of a project from conception to completion (including commissioning) on behalf of a client requiring the identification of the client's objectives in terms of utility, function, quality, time and cost, and the establishment of relationships between resources, integrating, monitoring and controlling the contributors to the project and their output, and evaluating and selecting alternatives in pursuit of the client's satisfaction with the project outcome" (Walker, 2002). Therefore, it is essential the project designer comprise the knowledge to correctly identify the different stages of the construction planning, as well as taking into consideration the logistics and resources involved in the project. Hadju, in network scheduling for construction project management, define the steps to create a good planning (Hadju, 1997):

(1) Task definition and description, considering the detail required;
(2) Task interdependencies definition and creation of a list of predecessors and successors;
(3) Network design, considering tasks' interdependencies;
(4) Resources and time estimation;
(5) Base calculations, including total project length;
(6) Advanced calculations, aiming a more efficient project, considering, cost, resources and task duration;
(7) Project control throughout its implementation;
(8) Project revision, considering the tasks, their duration and the necessary resources, with the intention of presenting alternatives to the established planning.

The steps one through five comprise the initial stage, six and seven consist of the scheduling stage, and the last is the project stage. The construction planning used in the implemented prototype is realistic and considers the designed and written documentation, measurements and quantities map, specifications and regulations with relevance to the project (Casimiro, 2006). On the present work, a prototype was developed supported on VR technology, where the construction of a building and the related sequence of activities are used (Levine, 2002).

VR IN CONSTRUCTION

Virtual reality technology is often considered a way to simulate reality through graphics projection, allowing the user to interact with their surroundings. In construction industry, from the conception to the actual implementation, project designs are presented mostly on paper, 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 (Grilo et al., 2001).

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. Some applications are already offering the possibility of communication between different specialties while developing a mutual project (Yerrapathruni et al., 2003).

The concept of building information modeling (BIM), considers the integration of 3D models with the planning of all aspects of the project, including resource management and logistics, with the purpose of reducing errors, and therefore costs, by using software to generate a accurate model of the final product, containing all the information needed to everyone involved in construction and maintenance. A BIM application is not only used to create the elements, but also as a manager of all the designs, uncovering construction errors when merging the different specialties. Applications like Autodesk's AutoCAD Revit Architecture Suite, AutoCAD Revit Structure Suite and AutoCAD Revit MEP Suite offer the possibility of different specialist working on the same project in different files and then combining then efficiently (Autodesk AutoCAD Architecture2011 / Civil3D /Revit http://images.autodesk.com/, 2010). One drawback of these 4D models is the amount of time needed to create them, as well as the lack of trained personnel to do it.

Other applications offer a different kind of communication, being more focused on manipulating than creating the model. EON Studio is one of these applications where, by programming actions associated with different objects within the model, the final user can experience the interaction and the virtual reality in the presentation (EON Studio, http://www.eonreality.com, 2010).

IMPLEMENTATION OF VR MODEL

A prototype concerning the management of the construction activity was created with the purpose to present a three-dimensional model integrated with its construction planning schedule (Santos, 2010). The application was developed in three stages: the planning, the modeling, and the integration of the first two stages:

(1) The planning has to consider the final purpose of the presentation, and the definition of the tasks and its detail has to be done according to this idea. Using Microsoft Project 2007, the tasks are introduced and the relations between them defined;
(2) The geometric modeling needs to relate correctly with

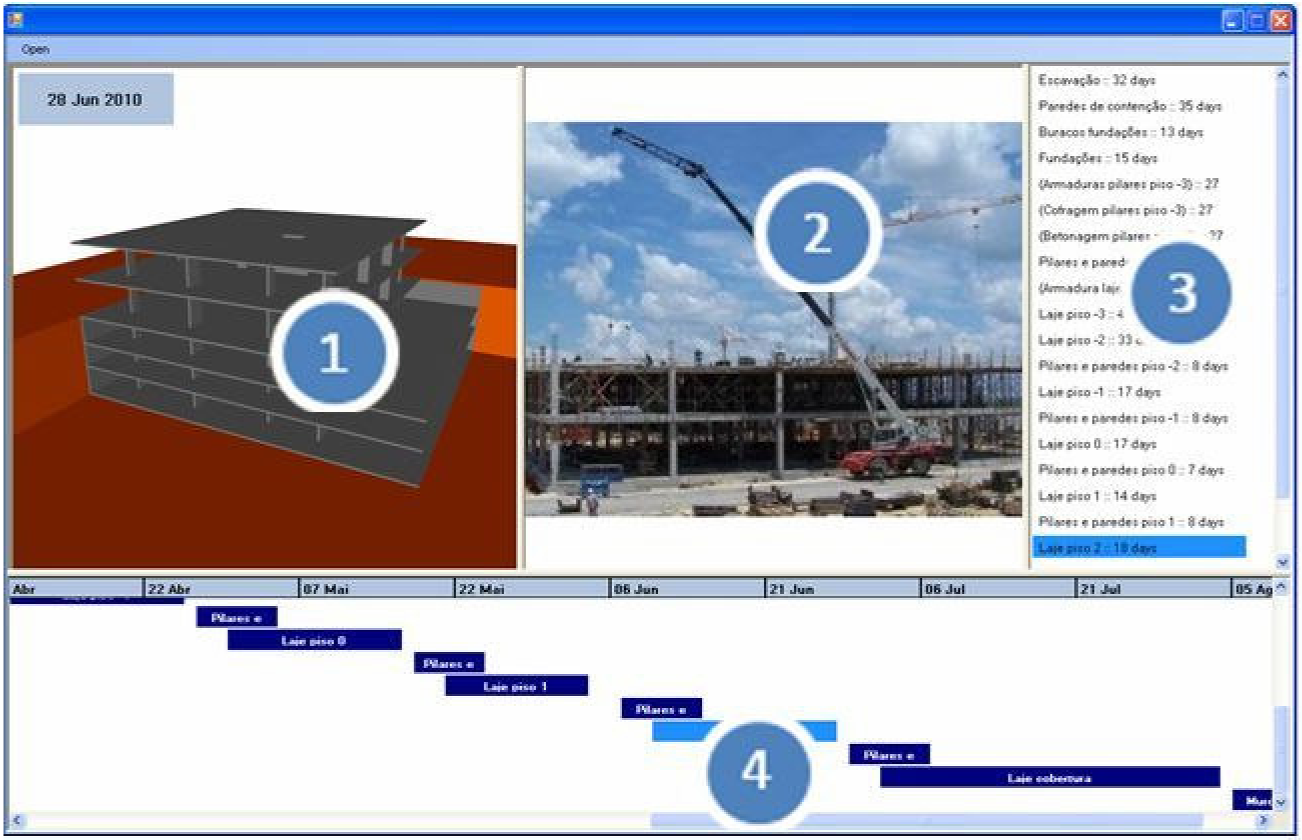

Figure 1. Application interface.

the tasks defined in the planning stage. Using AutoCAD 2010 as a modeling tool, the layers do the distinction between the different tasks and the elements are creating considering the detail necessary to the correct comprehension. The application also presents a real-time illustration of the construction evolution through photographs from the site, taken at specific points in time; (3) The third stage, the integration, makes use of two programs: EON Studio 5.0 and Microsoft Visual C# 2008 Express Edition, where the first takes the 3D model created with AutoCAD and introduces it in the application developed using the second. The application, developed in C#, integrates all the components described with the interface presented in Figure 1. The application has the following organization:

1. Virtual model;
2. Pictures of construction site;
3. Planning task list;
4. Gantt map

The interaction with the application is made through 3 and 4. Both the task list items and Gantt map bars are buttons that when pressed send the information to the EON about the task selected, and in return EON presents the model in the current state, this meaning that it shows and hides specific elements considering the construction's current stage.

EON can interact with the model in a number of different ways. In this prototype only the state of elements and position of camera is changed. The state of an element is presented by its hidden property, whether it is selected or not, whilst the camera position is determined by translation and rotation coordinates. EON Studio also offers the possibility to change the material associated with each element, creating a more realistic model.

Any new objects can be introduced in the application, just by modeling the new elements considering their position relatively to the ones already in the simulation and programming the associated action in EON Studio. Likewise, the application accepts any kind of construction project, as long as the imperatives of their implementation are met. Additionally, and with the appropriate models, it can also be used in construction site management.

PROGRAMMING DETAILS

This prototype's weakness is the time needed to make the preparation for the actual interaction with the application. Modeling a building may not be much extended. However, the programming of the actions in

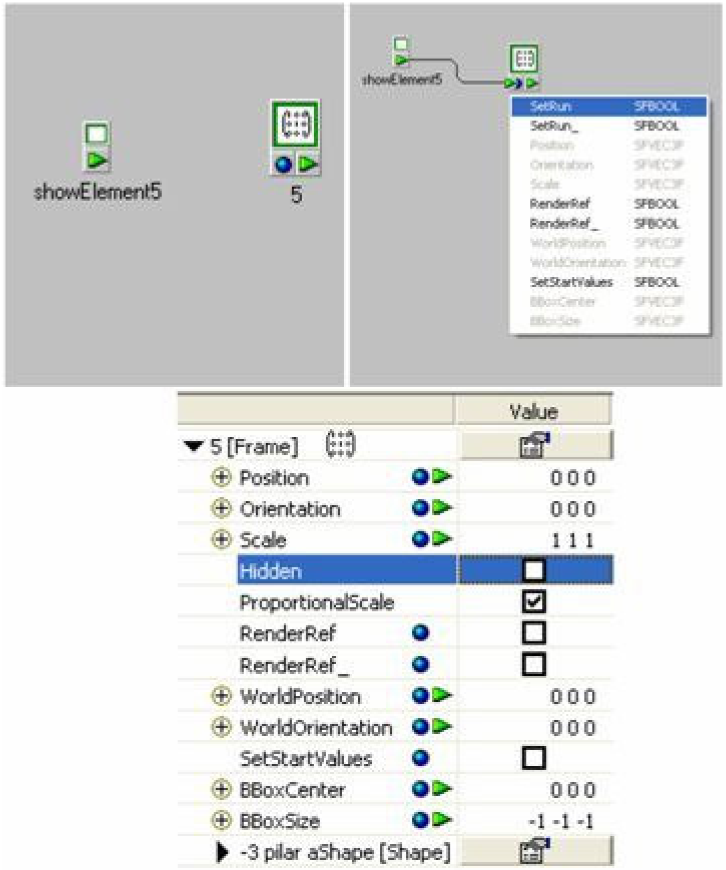

Figure 2. Hidden and unhidden instruction.

EON Studio can be time-consuming.

In the application, the geometric model of the building is presented in sequence simulating the construction activity. For that, each modeled component of the building is connected to the programming instruction: hidden and unhidden (Figure 2). This is one of the capacities allowed by the EON software. The command of unhide is linked to each step (label of the list of activities and bar of the Gant map) and to each geometric model. The identification both in the list/map and the related geometric model is established by a number. The number corresponds to the sequence defined in the design project. An action will begin when the user click over a label or a bar.

Figure 3 present a tree of links connecting the command of interaction (executed by the user) and the instruction show of the respective element (see the instruction *showelement_n* linked to the geometric model identified by the *n* number). In addition the control of the position and orientation of a camera (position, zoom and orientation of the model in relation to the observer) must be defined in accordance with the selected construction step. The position of the camera is controlled within the EON software as shown in Figure 4. A first position of the camera is defined in order to allow the user to visualize adequately the selected detail of the building (Figure 5). After that the user is free to walkthrough inside and around the model. For that the user must interact with the 3D model through the VR window of the interface.

THE CASE STUDY

As a method of testing the application, a construction project was implemented, particularly the structure of a building, using its graphic documentation, such as architectural and structural blueprints, the project description and construction planning (Figure 6). The whole project was simplified to meet this paper's academic purposes, and the list of tasks was defined considering the more characteristic stages in a construction process, and also a few tasks focused in construction details of certain elements (Figure 7). As a result, AutoCAD layers were created for each task defined and the 3D model assembled (Figure 8). When finished, the 3D model is exported to EON Studio, where a diagram of events is created, after what the application is ready to be used. As explained before, the task list and the virtual model are connected. When selecting a task, the relevant construction stage is presented (Figure 9).

The first scenario concerns the landscape and then the

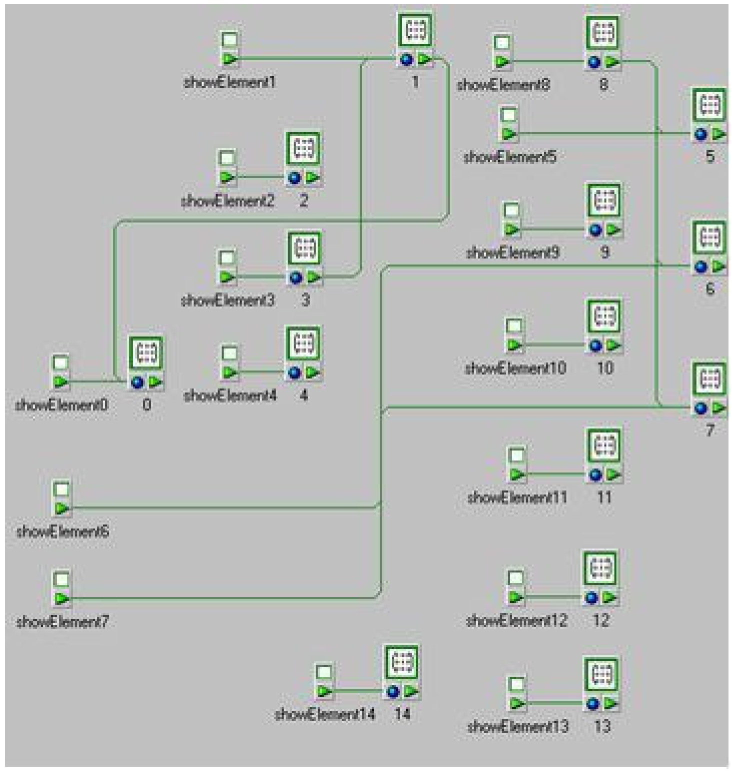

Figure 3. Diagram of actions hidden and unhidden for each element.

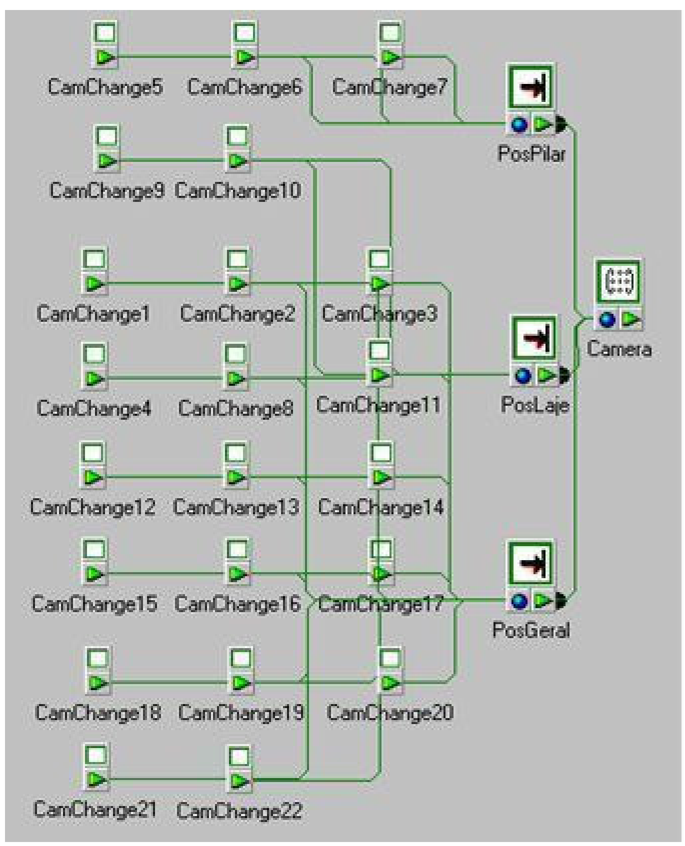

Figure 4. Control of the camera.

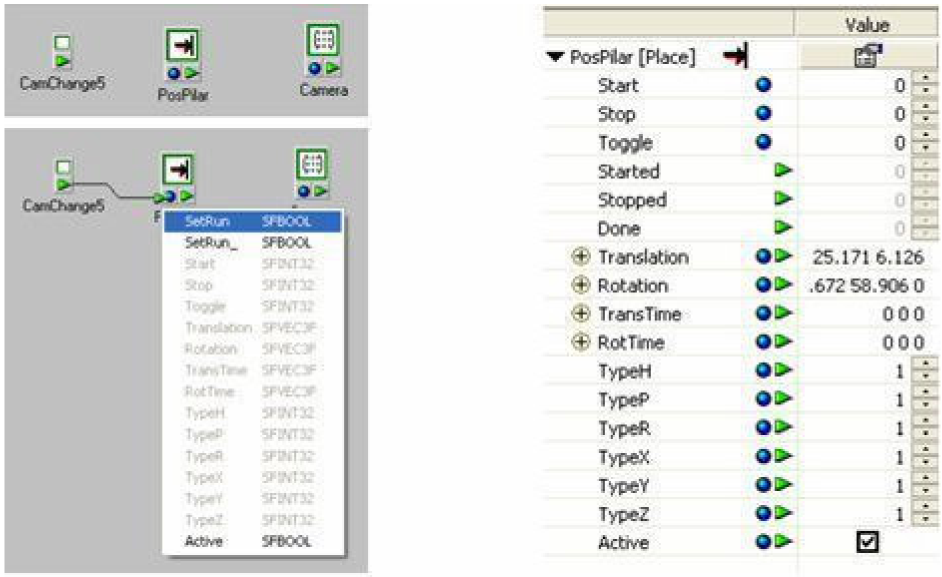

Figure 5. Control of the translation and rotation movements of the model.

	Name	Duration	Start	Finish
1	Excavation	25 days	Mon 23-11-09	Fri 25-12-09
2	Retaining walls	26 days	Wed 25-11-09	Wed 30-12-09
3	Foundation holes	10 days	Fri 25-12-09	Thu 07-01-10
4	Foundations	12 days	Tue 29-12-09	Wed 13-01-10
5	(Column reinforcement level -3)	20 days	Thu 07-01-10	Wed 03-02-10
6	(Column formwork level -3)	20 days	Thu 07-01-10	Wed 03-02-10
7	(Column concreting level -3)	20 days	Thu 07-01-10	Wed 03-02-10
8	Columns and walls level -3	20 days	Thu 07-01-10	Wed 03-02-10
9	(Slab reinforcement level -3)	23 days	Thu 14-01-10	Mon 15-02-10
10	Slab level -3	32 days	Thu 14-01-10	Fri 26-02-10
11	Slab level -2	24 days	Wed 03-03-10	Mon 05-04-10
12	Columns and walls level -2	7 days	Tue 06-04-10	Wed 14-04-10
13	Slab level -1	12 days	Fri 09-04-10	Mon 26-04-10
14	Columns and walls level -1	7 days	Tue 27-04-10	Wed 05-05-10
15	Slab level 0	12 days	Fri 30-04-10	Mon 17-05-10
16	Columns and walls level 0	6 days	Tue 18-05-10	Tue 25-05-10
17	Slab level 1	11 days	Fri 21-05-10	Fri 04-06-10
18	Columns and walls level 1	7 days	Mon 07-06-10	Tue 15-06-10
19	Slab level 2	13 days	Thu 10-06-10	Mon 28-06-10
20	Columns and walls level 2	7 days	Tue 29-06-10	Wed 07-07-10
21	Slab roof	24 days	Fri 02-07-10	Wed 04-08-10
22	Walls roof	9 days	Thu 05-08-10	Tue 17-08-10

Figure 6. Construction planning.

foundation work began (Figure 10).

In this example, some construction details were modeled, including one column progress. This progress is presented in Figure 11, throughout three stages. Not having a picture associated, the camera symbol becomes visible instead. A detail of the reinforcement and the concentration of a slab is presented in Figure 12. When constructing a building, the planning sometimes needs to be changed due to unexpected contingencies.

Implementing these changes in the prototype is actually

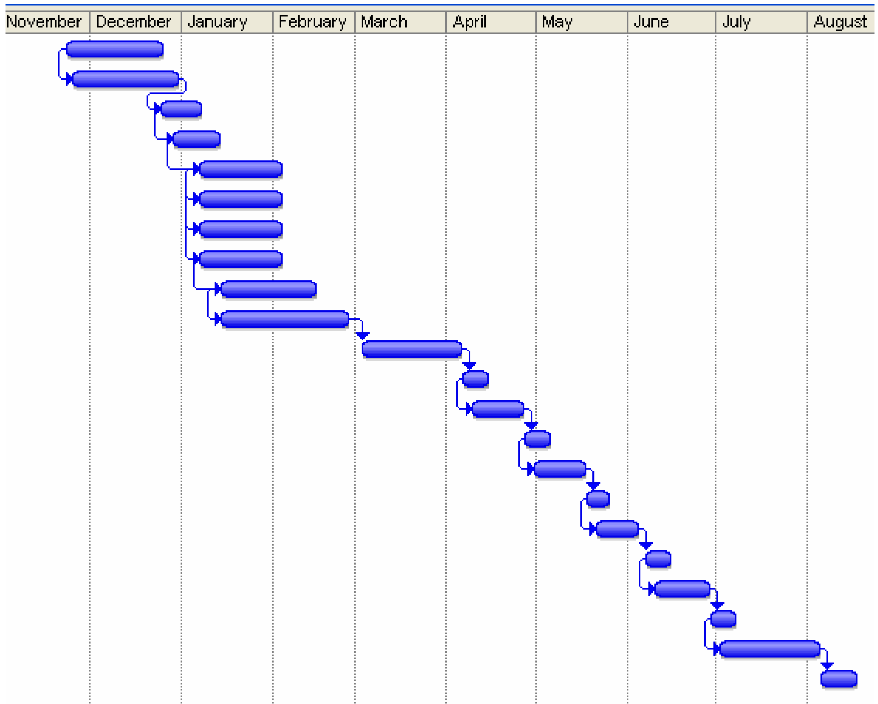

Figure 7. Gantt map.

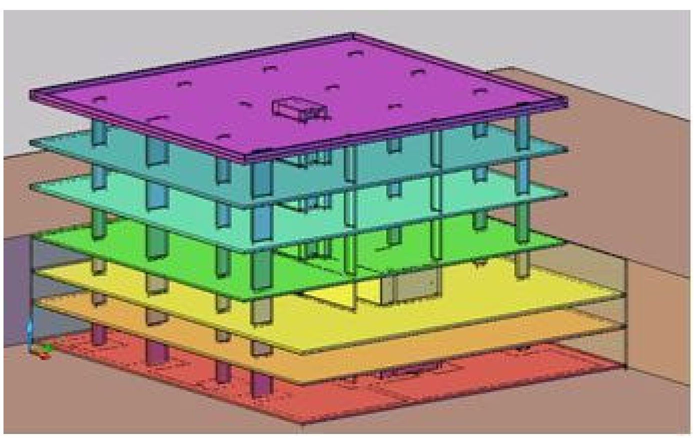

Figure 8. 3D model of the building structure.

very simple, as the user just have got to change the tasks new start and finish dates in MS Project and load the new file into the application. When a task is selected in the construction planning chart a static position of the model is presented. A first view is always linked to a task. This was established to provide an easier interaction with the 3D model, and to focus the attention of the user on the important sections on each task, guiding them correctly through the development of the construction.

Next, in order to obtain the same point of view of the photo, the user can manipulate the virtual model, choosing an identical perspective. So, visualizing what is planned and what was done in the real place, the construction work is better compared and analyzed (Figure 13). In addition the user can manipulate the model walking through the virtual building observing any construction detail he wants to compare.

All steps were modelled and linked to the planning chart. Details of the construction work are presented in Figure 14. The date concerning each visualized task is shown in the upper left corner of the virtual model window.

CONCLUSIONS

Technical drawings and explanatory texts often have little detail and are frequently insufficient in fully comprehend-ding the object. VR technology and its capability of interaction and connectivity between elements were employed in the prototype's implementation, offering several benefits both in presenting and developing projects. Mistakes can easily be caught before construction a start, which translates in time and cost reduction.

In this paper was introduced a prototype which purpose is to ease the control of construction planning throughout project's development. It can be used with any kind of construction project and, being a flexible application, accepts new data when necessary, allowing for a comparison between the planned and the constructed. The prototype can also be expanded to include other aspects of construction management, such as resource administration, or to have a real-time access to the

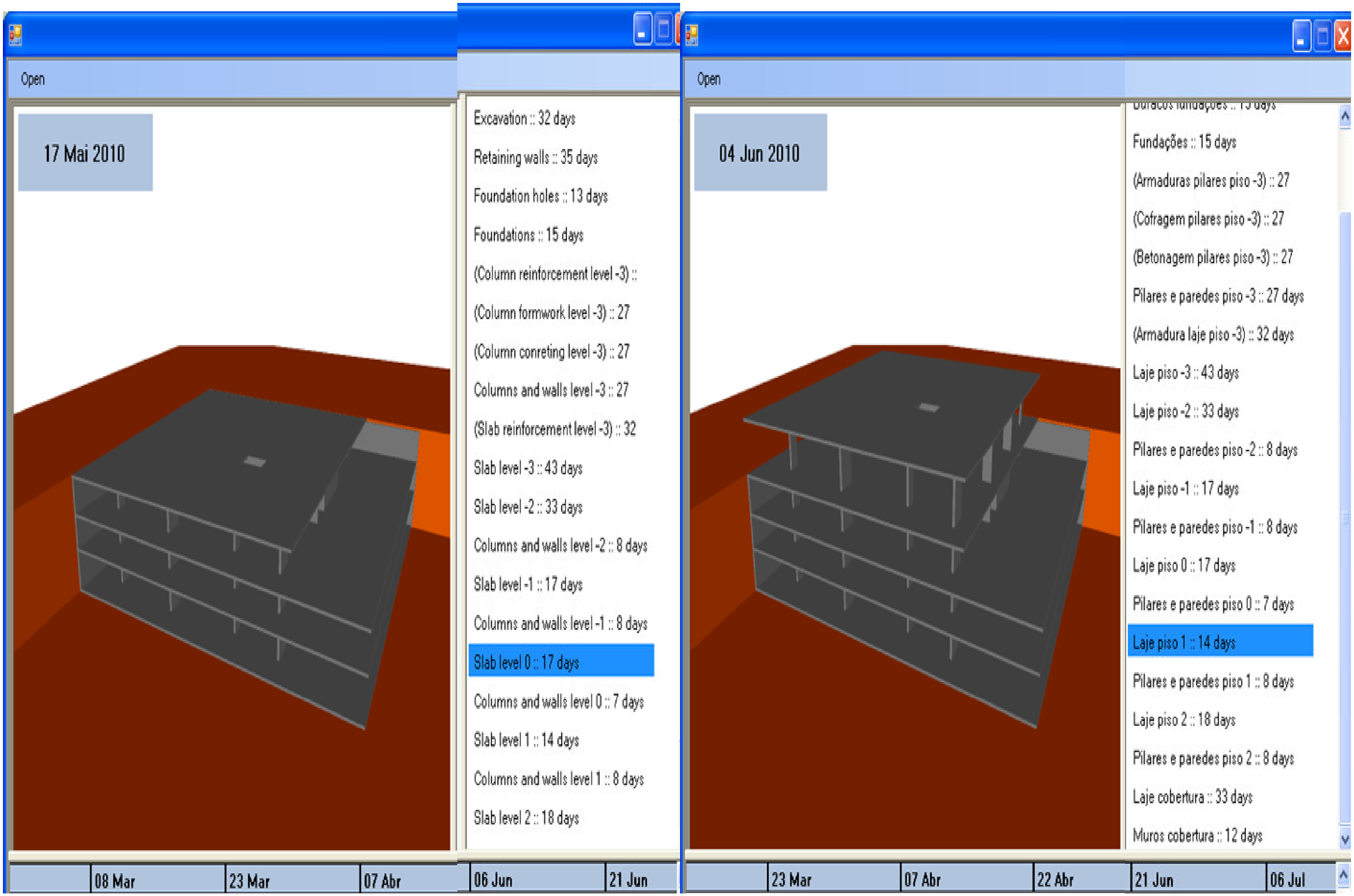

Figure 9. Application's virtual model and task list.

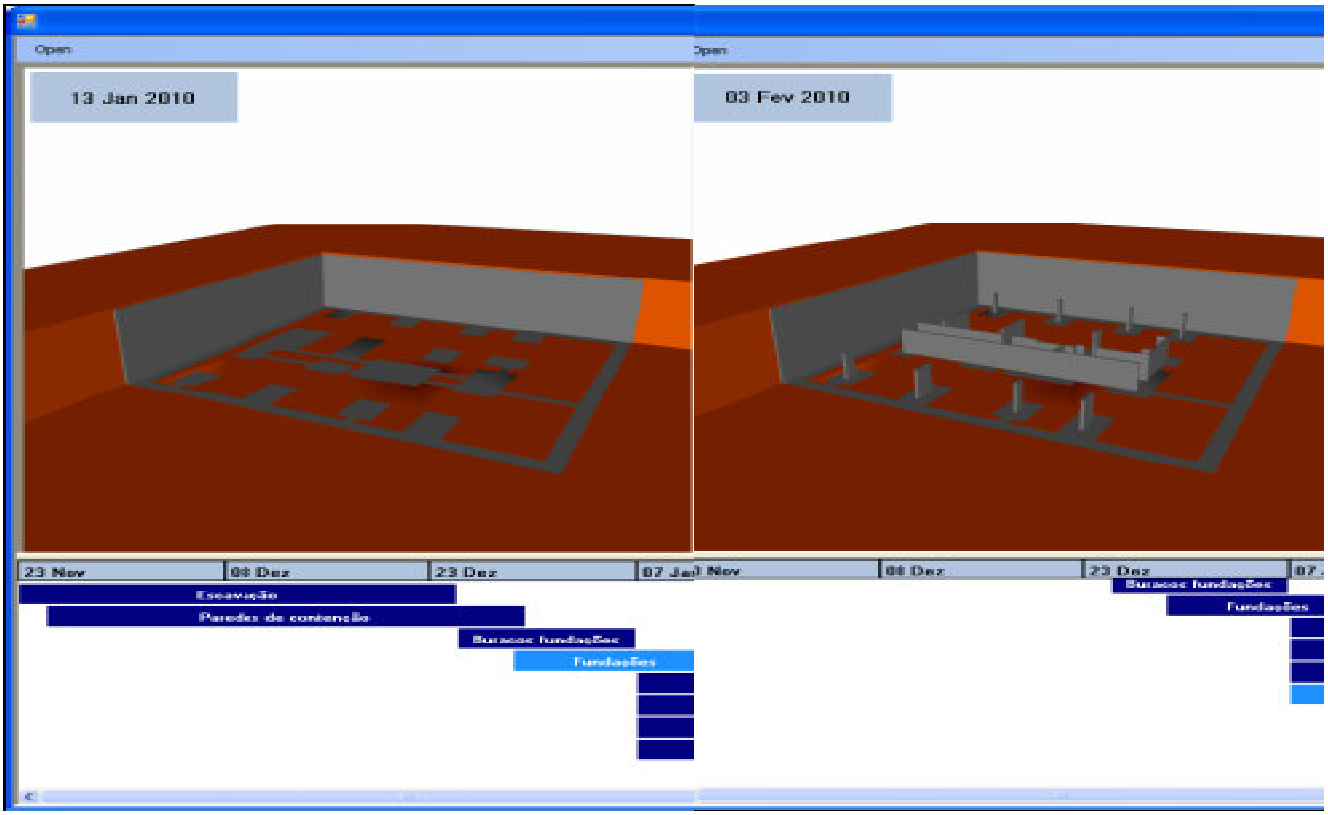

Figure 10. Visualization of the foundation work.

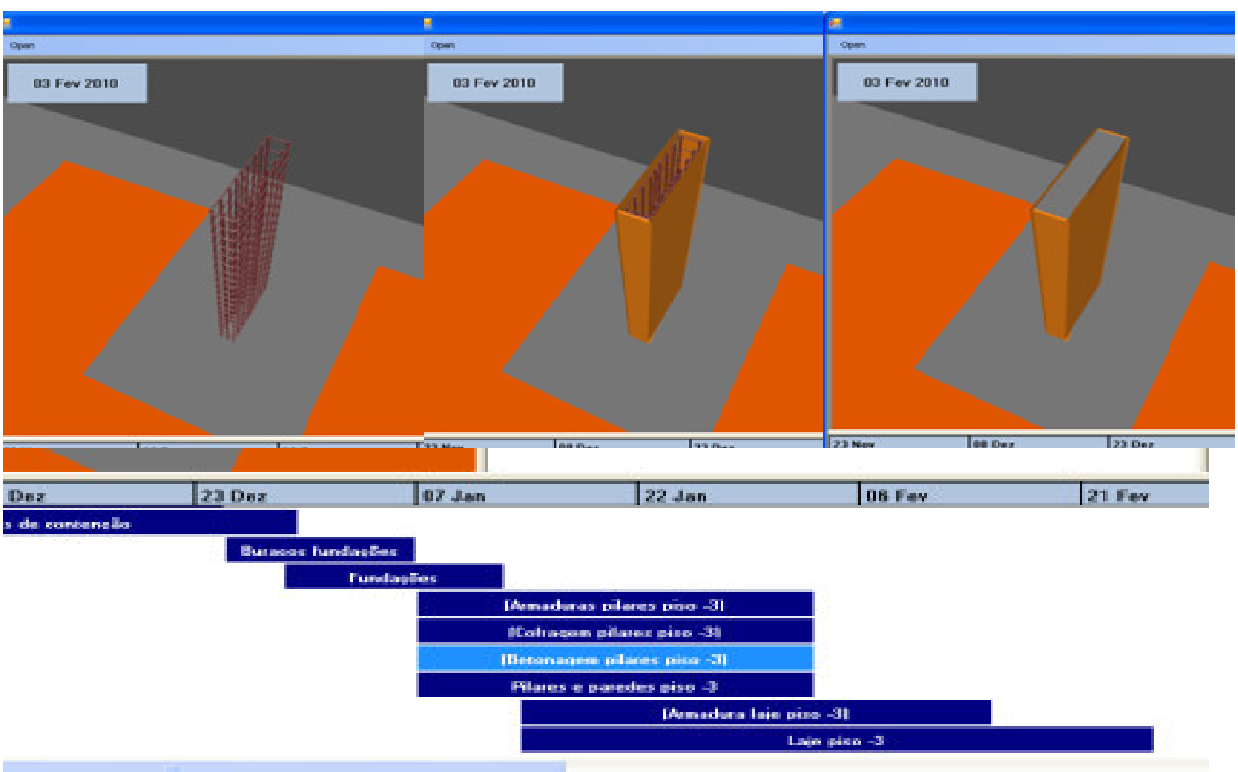

Figure 11. Column construction progress: reinforcement, formwork and concreting.

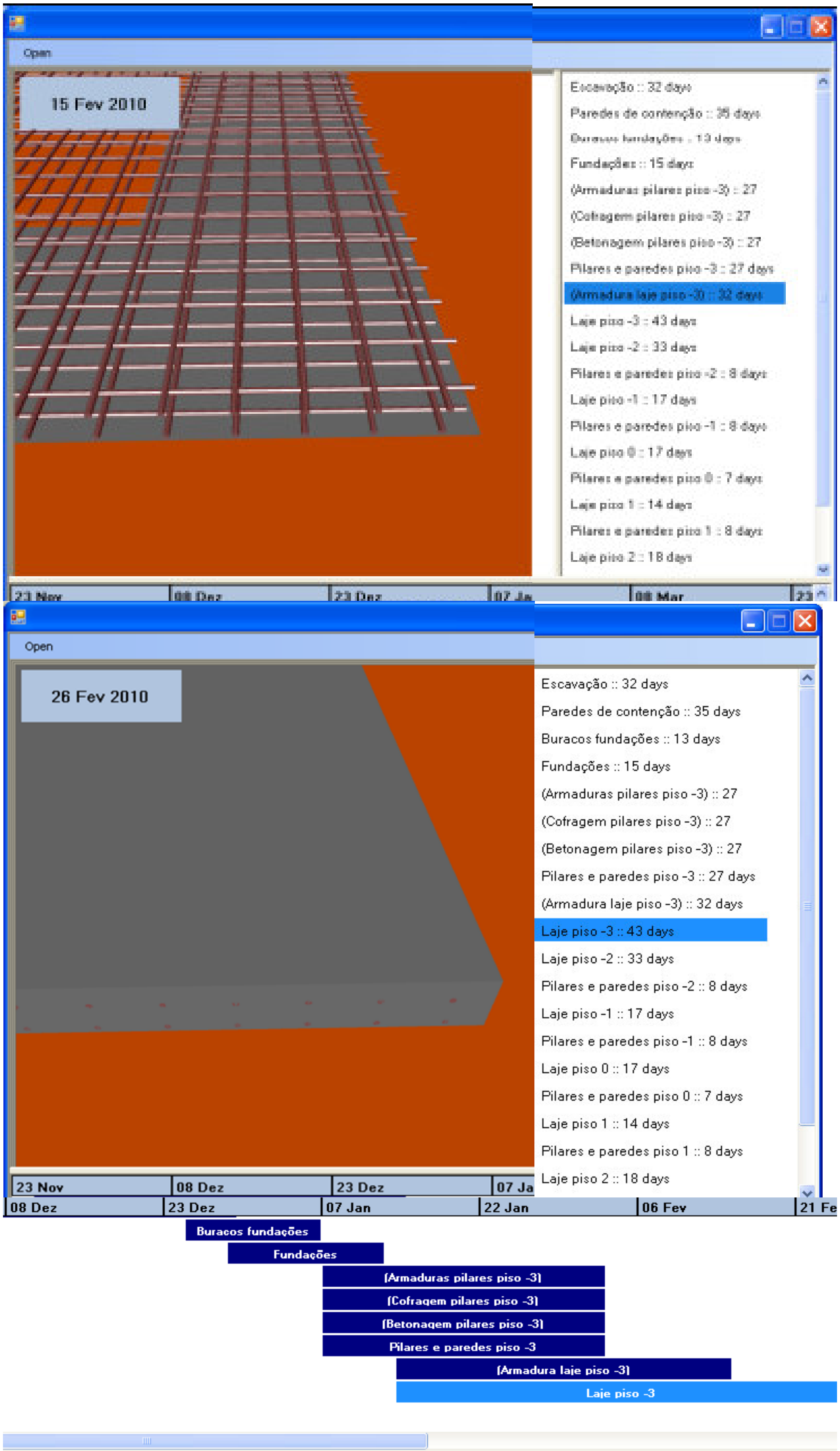

Figure 12. Construction of a slab.

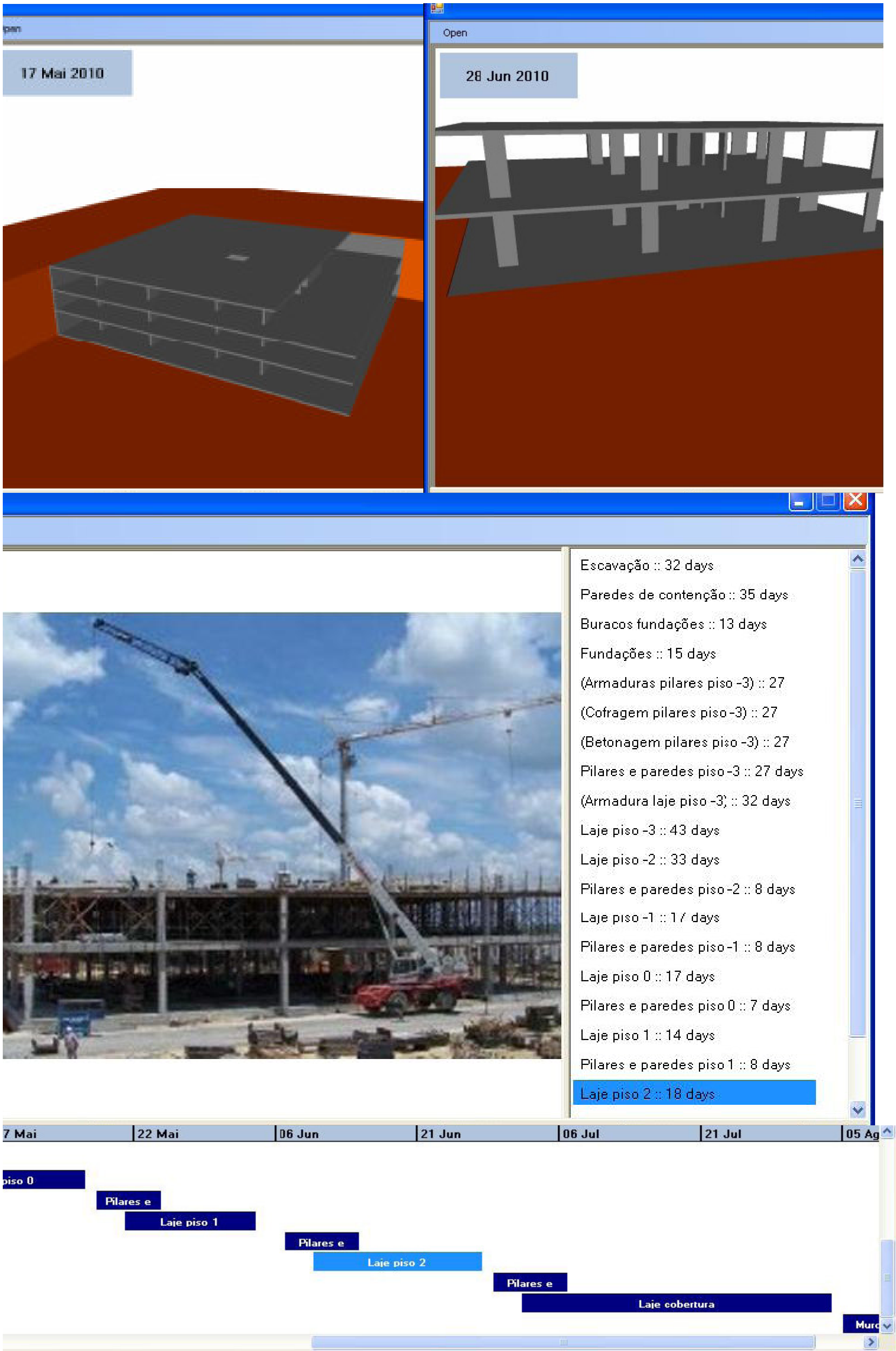

Figure 13. Rotation applied to the virtual model.

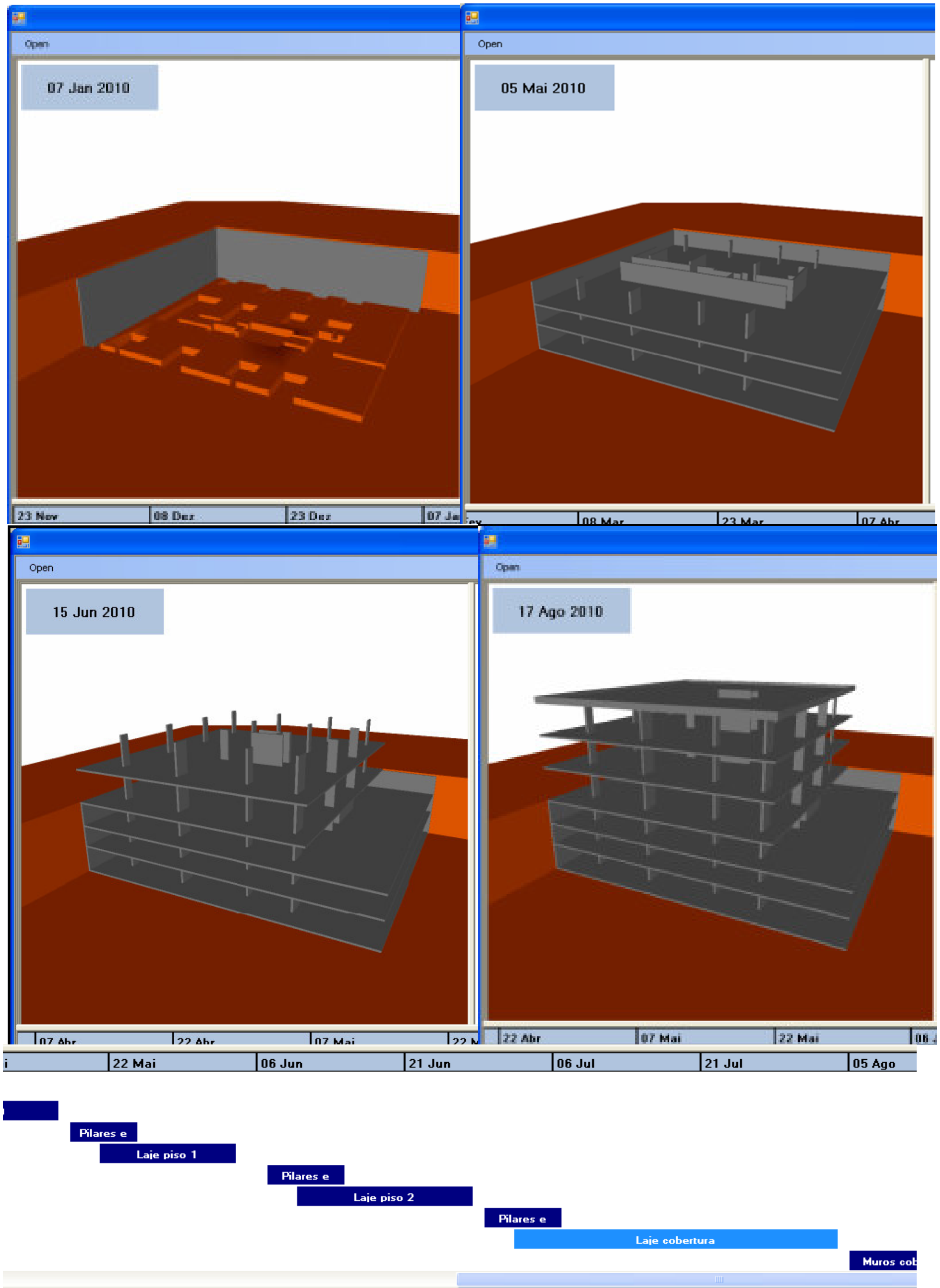

Figure 14. Sequence of the construction process.

construction, through the use of cameras installed on site. The use of new mobile technologies could move the application to the construction site, clarifying any doubts about location or position of each component.

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