Construction Planning Using 4D Virtual Models

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Abstract
Construction Management, has traditionally been focused in the creation of a timeline used more as a guide to the development of the construction, demeaning the importance of being integrated in its conception. Additionally, technical drawings are sometimes insufficient in object's total definition, and present themselves as an incomplete tool in transmitting the original idea. Geometrical tridimensional (3D) models offer a detailed analyses of the construction project and, when linked to the construction planning, clearly communicate the constructive process and comprise an important support in project conception and implementation.

This paper offers a global view about the application of 4D virtual models in Engineering, seeing that these are 3D models to which the time factor was introduced, with focus on Construction Management. Additionally, Virtual Reality (VR) technology is used, and presented as an innovative visual tool in supporting the project conception and a crucial element in developing the 4D virtual models. Being a simulation of the reality through the creation of graphic projection, VR permits a great deal of interactivity and the study of complex scenarios. Also, the communication between the project manager and the construction site is improved, promoting the dialog and interaction between all those involved, through the presentation of tridimensional models with more information, avoiding inaccuracies and building errors.

Bearing in mind the purpose of this paper, a prototype was designed, supported in Virtual Reality technology with application to Construction Management. This prototype, presented as a virtual application, intends to present the project in a 3D way, connected to construction planning, resulting in a valuable asset in monitoring the development of the construction activity, based on the construction planning designed.

Keywords
Virtual Reality, Construction Management, Virtual 4D Models, Evolutionary Models

1. Introduction
In Engineering, technical drawings have had, throughout times, a crucial role in communication between the numerous actors in a project. Generally, drawings represent formal solutions, and often incompatibility mistakes are only detected in advance stadium, on site, with additional costs which can be prevented.

In this area, 4D models, where the time factor is added to the 3D model, promote the interaction between the 3D model and the construction planning, allowing immediate perception of the work evolution. With planning, correct evaluation and adequacy to intervenient needs, 4D models are a positive contribution for supporting decisions when establishing planning strategies.
Moreover, Virtual Reality (VR) technology makes possible the presentation of the construction work evolution, both immersive and interactively. Virtual models allow total immersion with on-spot project correction, as many other options more or less immersive, more or less interactive, individually or together, allowing the project creator to use the one that most adjusts to the purpose and users.

On this paper context, a prototype was developed supported on VR technology, where the construction of a building and its phased planning is employed.

2. Management Study

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 take into consideration the logistics and resources involved in the project. The human resource is one of the most important resources in a project, and is, most of the times, neglected.

The construction management and its planning depends on the target, while the people in the construction site have the need for a more detailed presentation, the client may want something more general and wide-ranging. Hadju, in Network Scheduling for Construction Project Management [Hadju, 1997], define the steps to create a good planning, where one through five comprise the initial stage, six and seven consist of the scheduling stage, and the last is the project stage:

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 construction planning, introduced in this paper, must be realistic and have in account the designed and written documentation, measurements their and quantities map, specifications and regulations with relevance to the project. The purpose of the planning is an important factor as well, as the detail must be specified accordingly.

There are several different factors to consider in the process of planning:

- workscope;
- time;
- resources;
- costs;
- quality;
- communication;
- risk;
- contracts and procurement.

Levine, about the project management, mentions that the function involved in planning and control of projects (...) are just a part of the scope of project management. Add to this some of the soft skills, such as managing resources who report to other managers, using temporary or outsourced
personnel, communication with a wide span of involved or concerned individuals, on several levels, and satisfying multiple stakeholders, the task becomes rather large and specialized [Levine, 2002].

When going through the other factors, the stress is, most of the times, put on the triangle time-resources-costs [Casimiro, 2006]. These three factors are interconnected and interdependent. Time has a great significance in planning, as the tasks’ length must converge to a project duration compatible with the deadline. In defining the duration of a task the available resources must be considered. And this availability is intrinsically connected to the costs associated with the project.

Bearing in mind the optimal balance between time and costs, the two essential issues to avoid are outsourcing and periods of resources inactivity.

3. Virtual Reality Technology
Virtual Reality technology is often considered a way to simulate reality through graphics projection, allowing the user to interact with their surroundings.

VR can be immersive or non-immersive. Non-immersive VR is widely used in 3D modeling for Architecture or Engineering and in videogames, as it merely requires an adequate computer. Immersive VR makes also use of specific gadgets, like Head Mounted Displays (HMD), Data Gloves, Binocular Omni-Orientation Monitors (BOOM) or Cave Automated Virtual Environments (CAVE), as shown in Figure 1.

Immersive VR has application in medical diagnose and research, in producing mechanical virtual prototypes, in construction project and management, and in education.

The main benefit of virtual representations is the tri-dimensionality, allowing numerous points of view both inside and outside the simulated object. Different perspectives can be achieved using only one model, and including all the information necessary to the definition of the object, as shadows or textures [Grilo et al., 2001].

![Figure 1: Examples of gadgets used in immersive RV: 1) HMD [Virtual Realities, 2010], 2) CAVE [ProSystems, 2010], 3) Data Gloves [Virtual Realities, 2010]](image)

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 misinterpreted on the construction site. 3D models present an alternative to avoid inaccuracies, as all the information can be included with the necessary detail.

These models can be separated into two categories: the operations level and the project level. The operations level, yet in an early and theoretical stage, can be described as the integration between the virtual model and the planning, the equipment, the temporary structures and any other resources needed in the construction process, and its conception is a difficult task, although the final result can be really positive. The project level is easier to implement and is the core of this paper.

Computer systems used in construction for graphic representation have experienced a vast evolution, allowing new ways of creating and presenting projects. 4D
models, also labeled as 3D evolutionary models, permit a better comprehension of the project throughout its life, minimizing the information loss through the chain of events.

The 4D virtual models have been studied for their applications, and one example is the project developed in Columbia University which presents, using Virtual Reality technology, a step-by-step guide in assembling complex structures [Computer Graphics, 2009].

These kind of models linked to construction planning are not yet massive, although there are some examples of successful implementation, like the IKEA model, employed in various industries and with some applications in construction industry. These models reduce the incidence of errors by offering a virtual prototype of the object and the possibility of its study. Referred as “try before build” [Heng Li et al., 2008], this process attributes the task of assembling the different parts of the object to the client, hence reducing construction costs.

One other of the benefits of Virtual Reality 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.

Building Information Modeling, or BIM, is this 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 an accurate model of the final product, containing all the information needed to everyone involved in construction and maintenance.

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 them efficiently [Autodesk, 2010]. The 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.

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 [Reality Inc, 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.

4. Prototype Implementation
The prototype was created with the purpose to present a three-dimensional model integrated with its construction planning. The application was developed in three stages: the planning, the modeling, and the integration of the first two stages.

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.

The modeling needs to relate correctly with the tasks defined in the planning stage. Using AutoCAD 2008 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.

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 2.

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.

There are some limitations in the prototype, like the static position of the model. 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.

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 very prolonged, however, the programming of the actions in *EON Studio* can be time-consuming.

5. Implementation Example

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.

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 3).
As a result, AutoCAD layers were created for each task defined and the 3D model assembled (Figure 4). 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.

![Figure 4: 3D model of the building structure](image)

### Table: Task Overview

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation</td>
<td>25 days</td>
<td>Mon 23-11-99</td>
<td>Fri 25-12-99</td>
</tr>
<tr>
<td>Retaining walls</td>
<td>20 days</td>
<td>Wed 25-11-99</td>
<td>Wed 20-12-99</td>
</tr>
<tr>
<td>Foundation holes</td>
<td>10 days</td>
<td>Fri 25-12-99</td>
<td>Thu 07-01-10</td>
</tr>
<tr>
<td>Framing</td>
<td>12 days</td>
<td>Tue 28-12-99</td>
<td>Tue 15-01-10</td>
</tr>
<tr>
<td>(Column reinforcement level -2)</td>
<td>12 days</td>
<td>Thu 07-01-10</td>
<td>Wed 06-02-10</td>
</tr>
<tr>
<td>(Column formwork level -2)</td>
<td>20 days</td>
<td>Thu 07-01-10</td>
<td>Wed 03-02-10</td>
</tr>
<tr>
<td>(Column concreting level -2)</td>
<td>20 days</td>
<td>Thu 07-01-10</td>
<td>Wed 03-02-10</td>
</tr>
<tr>
<td>Columns and walls level -3</td>
<td>20 days</td>
<td>Thu 07-01-10</td>
<td>Wed 03-02-10</td>
</tr>
<tr>
<td>Slab reinforcement level -3</td>
<td>20 days</td>
<td>Thu 07-01-10</td>
<td>Wed 03-02-10</td>
</tr>
<tr>
<td>Slab level -3</td>
<td>20 days</td>
<td>Thu 07-01-10</td>
<td>Wed 03-02-10</td>
</tr>
<tr>
<td>Slab level -2</td>
<td>24 days</td>
<td>Wed 03-03-10</td>
<td>Mon 05-04-10</td>
</tr>
<tr>
<td>Columns and walls level -2</td>
<td>7 days</td>
<td>Tue 06-04-10</td>
<td>Wed 14-04-10</td>
</tr>
<tr>
<td>Slab level -1</td>
<td>12 days</td>
<td>Tue 21-04-10</td>
<td>Wed 30-04-10</td>
</tr>
<tr>
<td>Columns and walls level -1</td>
<td>20 days</td>
<td>Wed 05-05-10</td>
<td>Wed 14-05-10</td>
</tr>
<tr>
<td>Slab level -1</td>
<td>12 days</td>
<td>Wed 14-05-10</td>
<td>Mon 26-05-10</td>
</tr>
<tr>
<td>Columns and walls level 0</td>
<td>6 days</td>
<td>Tue 10-05-10</td>
<td>Tue 25-05-10</td>
</tr>
<tr>
<td>Shell level 1</td>
<td>11 days</td>
<td>Tue 21-05-10</td>
<td>Fri 04-06-10</td>
</tr>
<tr>
<td>Columns and walls level 1</td>
<td>7 days</td>
<td>Mon 07-06-10</td>
<td>Tue 15-06-10</td>
</tr>
<tr>
<td>Slab level 2</td>
<td>12 days</td>
<td>Thu 15-06-10</td>
<td>Mon 28-06-10</td>
</tr>
<tr>
<td>Columns and walls level 2</td>
<td>7 days</td>
<td>Thu 29-06-10</td>
<td>Wed 07-07-10</td>
</tr>
<tr>
<td>Slab roof</td>
<td>24 days</td>
<td>Fri 08-07-10</td>
<td>Wed 04-08-10</td>
</tr>
<tr>
<td>Walls roof</td>
<td>9 days</td>
<td>Fri 09-08-10</td>
<td>Tue 14-08-10</td>
</tr>
</tbody>
</table>

When constructing a building, the planning sometimes needs to be changed due to unexpected contingencies. Implementing these changes in the prototype is actually selecting a task, the relevant construction stage is presented (Figure 5).

![Figure 5: Application's virtual model and task list](image)

In this example, some construction details were modeled, including one column progress. This progress is presented in Figure 6, throughout three stages. Not having a picture associated, the camera symbol becomes visible instead.

![Figure 6: Column construction progress: reinforcement, formwork and concreting.](image)
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.

6. Conclusion
Technical drawings and explanatory texts often have little detail and are frequently insufficient in fully comprehending the object.

Virtual Reality 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 starts, 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 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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