4D Model for construction planning based on BIM technology

EXTENDED ABSTRACT

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Master's Dissertation in

Construction and Rehabilitation

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October 2015

Summary

The BIM methodology, which combines the parametric design, 3D images, element level information, coordination, communication and visualization within the whole building lifecycle, is changing deeply the way how information is managed within the construction sector. The integration of the 4D technology in the BIM methodology is the foundation of this work. In a first stage, and within the scope of this work, the Revit *software* is used to obtain a 3D model of the architecture and structure projects of a building. At a later stage, the BIM 3D model is exported to the BIM visualizer *Naviswork.* The 3D BIM model allows the visualization of the construction process simulation, before the building construction actually start. So it plays a key part in the construction management, reducing the project duration, as well as the project risks. A case study of a building was analysed and some limitations and benefits were carried out, contributing to the dissemination of the BIM methodology in the construction planning sector.

1. Introduction

A construction enterprise is traditionally broken in multiple stages and specialities, existing therefore different intervenients throughout its lifecycle, since conception up to maintenance and demolition. In a more traditional process, each player uses a different and non-integrated work methodology, as there is not a source of complete and updated information for the overall project. This lack of process integration is one of the main drivers for the loss of information and, causing a loss of value through each stage. Information is a key factor in management in the internal context, as well as the relationship with the exterior.

The evolution of the information technologies has contributed greatly with new possibilities of integration and communication at distance. In a sector, such as the construction, marked by the fragmentation and where multiple players exist, usually geographically disperse, this ability to communicate at a distance has been fundamental for sharing information. It is also fundamental to ensure the interoperability amongst the multiple software solutions that are used in supporting the project development.

The concept of Building Information Modelling (BIM) aims at improving the work methods used nowadays. This new approach is based essentially in the integration of processes, supported by an information rich three dimensional (3D) model which allows to seamlessly track the whole lifecycle of the enterprise. As such, it is also expected that the whole process becomes more accessible to the multiple entities that collaborate in the enterprise either in the present or in the future.

2. State of the art

The construction sector presents itself increasingly more demanding, dynamic and complex, where its sustainability depends on being more demanding in the different stages of the lifecycle. The BIM methodology delivers an important contribute in achieving higher quality levels, that allow as well a more effective control of the execution schedule (BIM 4D) and cost (BIM 5D).

2.1. Building Information Modelling

The BIM designation is often wrongly given to a 3D representation of construction products, when in fact, it is an information model where the functional and physical attributes of a project are managed, simulating its actual construction. BIM represents a new approach to the information management in construction.

BuildingSMART (2010) defines BIM as "a set of information that is structured in a way that the data may be shared. BIM is a digital model of a building in which the information regarding a project are stored. It might be in 3D, 4D (by integrating time) or even 5D (when costs are integrated) up to 'nD', a term that covers any other level of information."

The work processes that involve BIM tools, develop around a 3D model where the relevant information is integrated, namely the information related to the identification and localization of the building elements, relationships amongst the elements and materials amongst others. This model allows a consistent way to produce and update the drawings as well as an automated extraction of list of quantities and analytical activities. Another potentiality of this tool is the increased ease in detecting incompatibilities and/or conflicts amongst the different speciality projects (Lino et al., 2012).

The BIM methodology is based in the 3D construction modelling, through the use of parametric objects that contain the necessary information to the proper understanding and communication of the project through the different actors. The development of the three dimensional model varies according to the goal and desired level of detail.

2.2. Parametric modelling

The objects used in BIM modelling represent the components of the actual building. According Eastman et al. (2008) the parametric objects in BIM have the following attributes:

- They consist of geometric definitions, associated to rules and data;
- Its geometry is integrated and non-redundant, maintaining the consistency of the object dimensions both in floor plant and elevations.
- The parametric object rules, modify automatically the associated geometry when inserted in the building model or when changes are made in the associated objects, to reflect any impacts.

- Objects may be defined by different levels of aggregation, enabling the definition of an entity based on their base elements. E.g.: in the entity “Wall”, if the specific weight of one of its components is changed, also the total weight of the entity “Wall” is also changed.
- Objects have the ability to receive or connect to a vast variety or even sets of properties and attributes.
- The user has the ability to develop its own parametric objects by means of creating object class libraries.

2.3. Interoperability

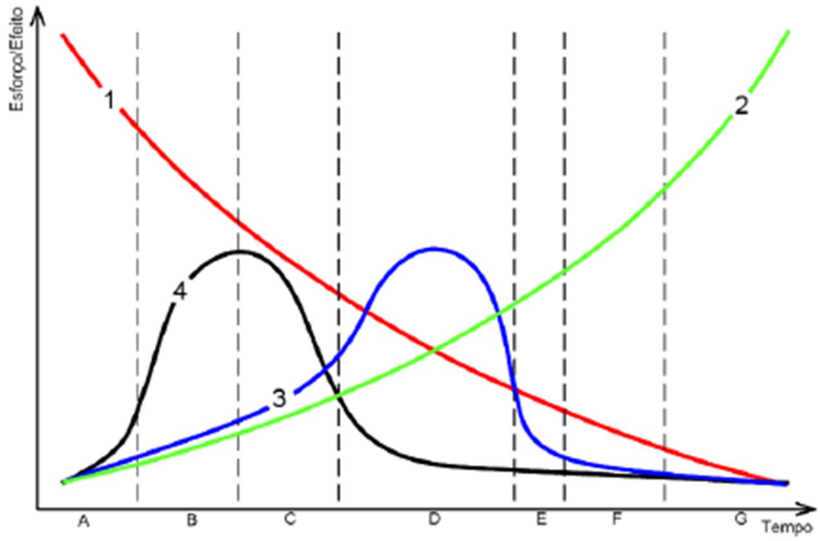
The conception and construction of a building is a team activity, both within a speciality and across specialities, being therefore important to ensure a good communication and an efficient exchange of information amongst the different actors. Within a collaborative environment, which is the goal in BIM methodology, it is crucial the sharing and exchange of data between the different players in the project and consequently amongst the different used software solutions.

The IFC standard, whose goal is to promote the interoperability amongst BIM applications, presents an open and independent format, compatible with the different BIM applications and defined in the ISO 16739:2013 “*Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries*”. It presents standardized specifications for BIM, with the goal of allowing the seamless transfer of the geometric properties as well as all the information associated to an object. This format first appears in 1994, when multiple companies and entities worked together in the path to create a universal standard. This is currently being promoted by *BuildingSMART – International Alliance of Interoperability,* whose objectives are the definition, publication and promotion of the IFC specification, for data sharing throughout a project lifecycle. The IFC standard specifies, in addition to the graphical elements, the complete properties for an object, such as its 3D characteristics, material and the relationship with other objects.

2.4. BIM Implementation

The implementation of a BIM methodology requires a change in the mind-set and in the ways of working requiring therefore training and resource availability, both human and financial, creation of contents, teamwork and new workflows. It must therefore be implemented in a multiple phases (Succar, 2009). The BIM methodology does not necessarily reduces the workload associated to the development of an endeavour, but facilitates the early detection of errors and incompatibilities, as well as the decision making process in early stages of the project development, where the impact of any changes is lower. In fact, the later in the construction process the changes occur, the higher are their costs.

Figure 1 shows the MacLeamy curve, representing the difference in effort between the traditional and the integrated process in the different stages of a project, as well as the impact of changes in the different project stages.



MacLeamy curve legend :

1- Impact in costs and functional project aspects;
2- Cost of project changes;
3- Effort distribution in the traditional process;
4- Effort distribution in the integrated process;

A- Promotion (*pré-design*);
B- Initial study(*schematic design*);
C- Development (*design development*);
D- Execution (*construction documentation);*
E- *Procurement;*
F- Construction Management;
G- Operação.

Figure 1 – Advantages of the early decision making in a project. MacLeamy curve.
(adapted from CURT, 2004)

For a successful BIM implementation Succar (2009) identifies the following stages of maturity in BIM implementation:

- Pre BIM stage, where there is still a big level of dependency on 2D drawings. Even if 3D visualization exists, the project data does not derive from the visualization model not the objects are interoperable with all the other surrounding objects.
- Level 0 – Modelling based in models that are mainly used to generate and coordinate automatically the 2D documentation with the 3D visualization, yet without parametric attributes. Usually at this stage, the users begin to see the potential of the BIM methodology.
- Level 1 – Model based cooperation, in which all actors cooperate actively with actors from other areas and disciplines, existing interoperability in the exchange od models amongst the various actors. At this level, the models begin to touch the 4D (planning) and 5D (budgeting).
- Level 2 – Network based integration, where the models are integrated, rich in semantic attributes. The models are created, shared and updated through collaborative processes throughout the different building stages. The relationships amongst all involved parties and

process flows are documented and contractually recognized. This level of maturity facilitates the path to the *Integrated Project Delivery* (IPD);

- Level 3 – IPD, which is a project approach that integrates people, systems, business structures and professional practices in a process that explores, in a collaborative way, the talents, potentials and ideas from all actors, with the goal of result optimization, reducing waste and increasing the efficiency in the whole enterprise lifecycle.

In the last few years, we have been faced with a significantly increase in the implementation of the BIM methodology in the architecture, engineering and building industry. Some countries have developed standards or guidelines for the usage of this methodology, for instance in the United States, Finland, Norway United Kingdom or Singapore. In some of these countries, the usage of the BIM methodology is mandatory for public sector projects. Currently there is no legislation in Portugal nor are guidelines for the usage of BIM, however there multiple initiatives that look for the best practices that might be used as guidelines in the BIM implementation.

3. Construction planning

The planning of the construction is a crucial stage in the conception of the enterprise, and involves the selection of technologies, definition of work activities, estimation and resource management, logistics and duration of each individual task, as well as all the dependencies amongst the different tasks.

The construction of a building has a sequence, with preceding and succeeding activities. An activity has a duration, the preceding activities are the ones that begin or end before this one starts, and the succeeding ones are the ones that depend either of the start or end of this activity. Based on these relationships, we identify the following four types of cross-dependencies. Additionally, each dependency might have a lag or a lead time (Henriques, 2014).

- **Finish to Start:** B may only start *n* days, after A has finished. *N* might be positive or negative, depending on the addition of lead or lag times.
- **Start to Start:** B must start *n* days after A has started;
- **Finish to Finish :** B must finish *n* days after the starting of A;
- **Início – Fim:** B can't finish before A starts.

Planning and scheduling in construction, involves the sequence of activities both in space and in time, taking into account the allocation and resource acquisition, quantities and space constraints amongst others. The estimation for the duration of the activities is a decisive stage for a good project and building planning, as the control of the schedule, depends on the proper effort and duration estimation.

4. 3D BIM Model

In order to explore the BIM tools, a 3D modelling was created of an already built building, built using the traditional 2D process. Only the architectural and infrastructure models were created using for this purpose the Revit software.

The modelling process begun with the creation of the architectural BIM components, starting the original 2D floor plants, given by the project team. Shortly, the 3D modelling followed these steps:

- Creation of reference plans that represent the floor levels
- Inserting into Revit the *dwg* drawings that will act as a foundation for the modeling.
- Creation of *grids* that represent the structural axis and act as references between the different models.
- Creation and definition of the multiple model elements, such as walls, windows, doors, pavements, stairs, etc… these elements are comprised by different shapes:
  - Duplication of standard Revit elements, and subsequent change in the properties.
  - Duplication of “Model in-place” components.
  - Creation of different typology families, such as walls and windows, for instance. The main advantage of using families, is that they are parametric and might be stored and re-used in different projects.
- Placement of the different created elements, according to the specifications of the project;
- Assignation of annotations and dimensions in different views, such as floor plants and elevations.

Figure 2 shows a 3D model perspective of the case study building.

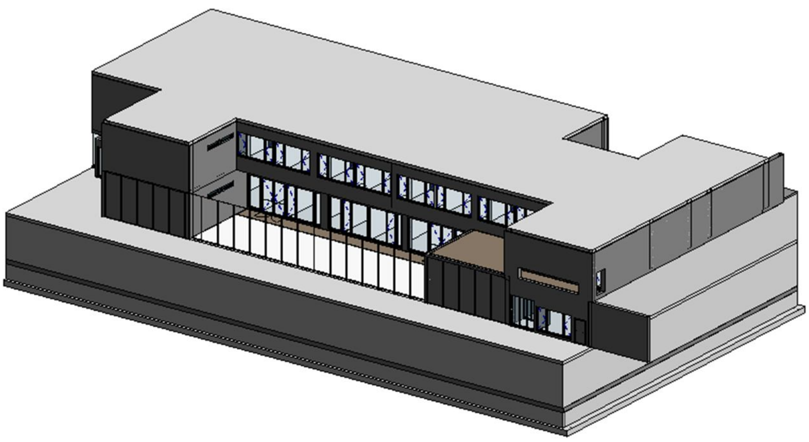


Figure 2 – Perspective of the 3D model (Architecture and Structure)

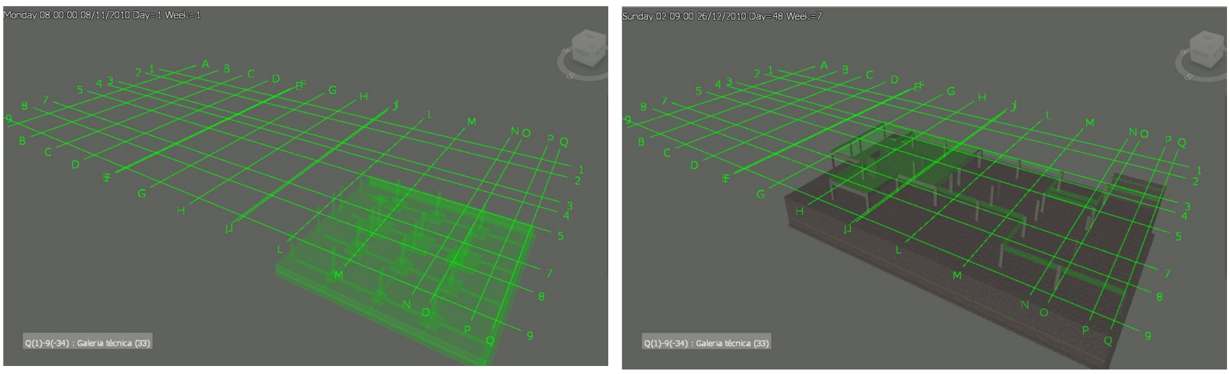
5. 4D BIM MODEL

The construction planning is a key activity in the design of a construction enterprise, involving the selection of technologies, definition of tasks, estimation and resource management, logistics and duration of individual tasks, as well as all interactions between the different tasks. In practice, planning is a reflection of a mental process for defining tasks that are associated with the spatial, time and sequential data.

The 4D model allows the addition of time associations to the three-dimensional elements, allowing the visualizations and analysis of the activity sequence for the construction, before it actually starts.

To generate the 4D model for this case study the Navisworks software was used. This software allowed the interconnections amongst the 3D models created in the planning, where this solution built the interconnection of 3D models with planning in MS Project. Briefly, the steps for the preparation were:

- Export of Revit 3D models, in this case through an add-in for NWC format;
- Export the MS Project planning to the Naviswork timeliner;
- Group the three-dimensional elements of the models according to the tasks defined in the planning. For this purpose, “sets” were created. These "sets" can be created by selecting the elements directly on the model, by executing "tree selection" or by searching for its properties;
- Associate the created "sets" to the planning and schedule of tasks;
- Set for each task its category, that is, whether it is construction, demolition, temporary activity or another;
- Visualize the planning simulation. Figure 3 shows a couple of frames, extracted from the simulation of this project.



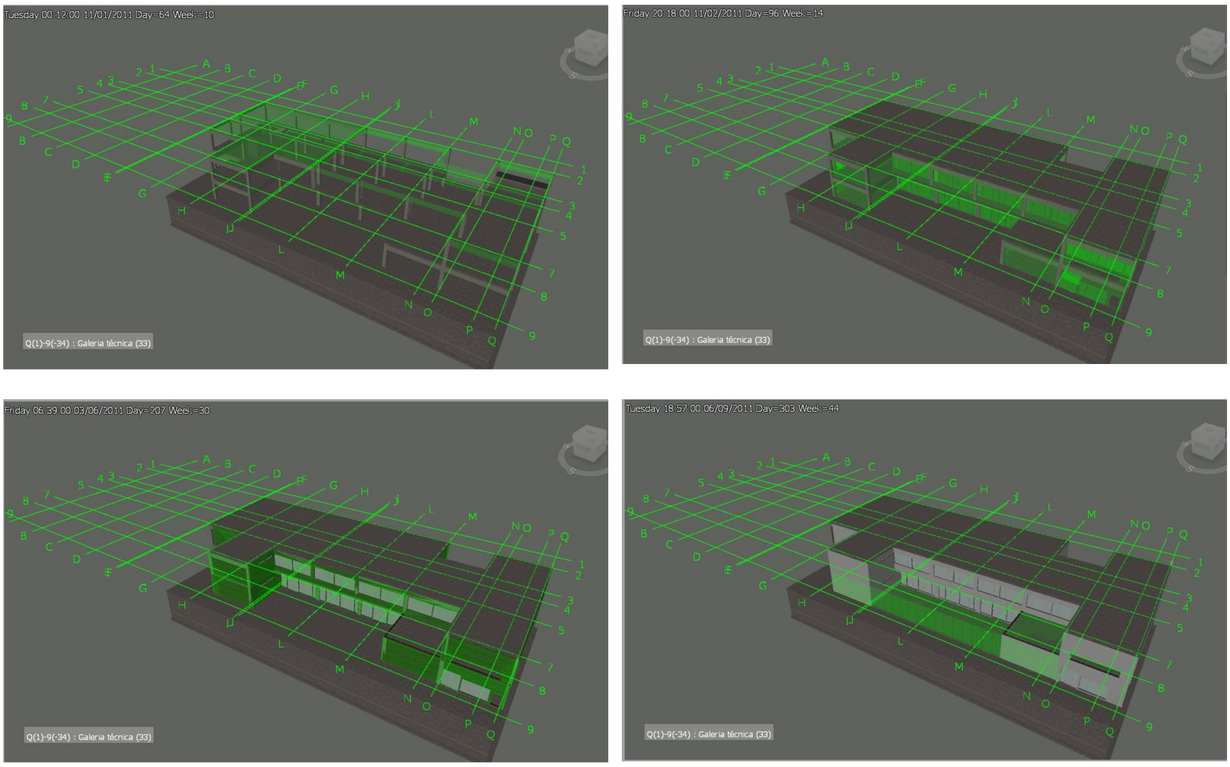


Figure 3 – Naviswork: planning and construction simulation screenshots.
(Green shows the elements that are currently being built.)

6. Final consideration

The BIM methodology created a great opportunity in the engineering, architecture and construction world, as it facilitates communication, interpretation and execution of the projects. Modelling in BIM is to actually model information.

The practical part of this work fell mainly in study of the 3D modelling using Revit, and applying a model for 4D construction planning. In this case Naviswork software was used. The simulation will probably never match the reality, with its unforeseen, but this motivates the development of visualization technologies, trying to reduce the gap amongst the digital world as the reality. The aim is to minimize the number of execution errors, at least those believed to be predictable.

During the usage of this tool, some very positive points where found, from which the following ones are highlighted:

- The ability to visualize the schedule and the 4D simulation show that Navisworks can be a useful tool to support the project planning, in a collaborative environment, as intended in the BIM methodology. The schedule can be continuously displayed as it is generated and changed in a flexible manner;

- As Revit and Navisworks are both products from the same software house (Autodesk), the interoperability is very good. All the element data from the 3D models are also available in Navisworks.
- The possibility to use a workflow which include 3D element parameters in the 3D model elements, similar to the respective tasks, simplifies the automated grouping through automatic selection rules. .
- The ability to navigate through the model allows to analyse each corner and each location of this model or from a group;
- Navisworks allows the option to import data in IFC, which is an interoperable model. It also has the ability to export in many other formats, in order to share the project data and the 4D modelling.
- The reduction in size, when compared with the original file, is also a strength, as it facilitates the model navigation.
- *Navisworks* also has the potential to provide support in the analysis and detection of conflicts amongst the speciality projects. In the scope of this work, this functionality has not been explored.

Nevertheless some improvement points were also identified. Solving this topics might allow a deeper and faster dissemination and implementation of this tools.

- Although the preplanning is flexible, it is not possible to perform changes in one single centralized location. Any changes required in the scheduling, require a tool such as MS project to actually perform the re-schedule. It is required to jump through 3 different software solutions: Revit – MsProject – *Navisworks*;
- The division or grouping of the model in areas or groups, must be made in advance in the 3D model, as well as any parameter that may be necessary, in order to facilitate the construction simulation process, which can be considered a weakness, as sometimes it may not be practical to have these elements separated in the original model. The designers usually do not have information regarding planning, which will be done at a later time. As such it may be necessary to adapt the project template to obtain a model that is a more focused in construction planning.
- On top of the above issue, planning supporting modelling ought to be executed in such a way that its elements are possible to be selected in an automated manner, for instance, through its properties, so that in the eventuality that the 3D model needs to be changed or updated, the links created in Navisworks aren’t lost or broken. If the sets are created via manual element selection, when one of the models is replaced, we might lose those connections. However, keeping the same filename e the file location, using the option “Merge” those links tend to be kept.
- The schedule could be more closely integrated in the BIM 4D tool, allowing for instance the possibility to allocate resources and define task precedence. This would allow that all the

process of planning would be performed straight in one single software, allowing a greater cost and critical path control, for instance.

- Tasks performed inside the building are difficult to visualize if they are planned for a date that is later than building the façade. This might be minimized setting transparency in some elements.

7. Conclusion

The BIM methodology has been opening new possibilities in the Engineering, Architecture and Construction world, as it facilitates the communication, sharing, reading and the execution of projects. Creating a BIM model is actually information modelling. This methodology aims to improve the information management between the intervenients in the project and construction process.

The 4D model elaborated on Navisworks allowed to conclude that the software meets many of the features inherent to construction management. The quality of the 3D models is important for the success of the process, as well as the designation and properties of elements and the construction activities, to expedite the process. The 4D model allows a visual analysis of the construction simulation, supporting the decision making process, in a collaborative environment. The construction simulation aims to minimize the number of execution errors and to facilitate the communication between the different project phases, planning and construction. The tools used in this case study have proven to be an added value, in construction planning.

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