2 Simulation of Construction Processes as a Link Between BIM Models and Construction Progression On-site

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Abstract

Among Information and Communication Technologies (ICT) developed in the past decades—and successfully applied to Construction—is Building Information Modeling (BIM). One possible use of BIM models is Phase Planning (4D modeling), i.e., the integration of schedule with 3D building components of the BIM model. In addition, there is the growth in the use of: (1) technologies, such as augmented-reality equipment, to bring BIM models to the field; (2) sensor networks to feedback data about the daily progress of construction work on-site. However, the connection between 4D models, and real-world data from sensors on the construction site, to promote integration between design and construction (among other possible applications) is still in its infancy. The question addressed by this research is: how to use simulation as a link between 4D BIM models and a network of sensors on-site (off-site)? Simulation would be considered as a set of interlinked models of different construction processes, which should evolve in time based on (partial) data received from sensors. In that context, the objective of this preliminary work is to study and validate the level of detail in one construction process model, necessary to incorporate one specific type of sensor, and to quantify, even if indirectly, the amount of progression in construction work on the field. Given the availability of the ProModel software, the present research aimed to develop different models of the same construction process, with different levels of details, to draw conclusion that could be extrapolated to other processes.

Keywords

4D BIM • Simulation • Construction process modeling

2.1 Introduction

Among Information and Communication Technologies (ICT) developed in the past decades—and successfully applied to Construction—is Building Information Modeling (BIM). BIM should not be just a set of computer tools to produce, communicate and manage construction information, but entirely new processes inside Architecture, Engineering, and Construction (AEC) industry around information models [1]. Some authors refers to these processes using BIM as Virtual Design and Construction (VDC) [2]. VDC processes emphasize the integration between design and construction through an information (BIM) model, and explicitly represents construction processes [3]—other researchers had emphasized the necessity to have construction processes models, beyond the current and common product data model natural to BIM [4].

One possible use of BIM models is Phase Planning or 4D modeling [5], i.e., the integration of schedule with 3D building components of the BIM model. When “comparing traditional project scheduling tools like CPM networks and bar charts

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with 4D modeling" [6], among the benefits of using the latter is the visual details that are possible based on a different representation.

In addition to this context, there is the growth in the use of technologies, such as augmented-reality equipment, like Microsoft Hololens and Daqri smart helmet, to bring BIM models to construction site. Also, the use of drones, video cameras, and laser scanner equipment are starting to bring more data about the daily progress of construction work on-site, which could be feedback, for example, for comparing real versus planned 4D models. Clearly, there is the possibility to stablish a bi-directional link between BIM model platforms and construction progress on-site [7].

However, as BIM processes around the world is increasingly being implemented, one point that is still in its infancy is, in fact, the connection between the 4D models, and real-world data from sensors on the construction site. Moreover, what would be the benefits in committing to more detailed or even discrete-event models for construction processes simulation, to enable such link?

The possibility to simulate on-site (and off-site) construction processes on computer systems could generate tools to better plan, monitor and manage construction work [8]. As the complexity of one single model to represent all construction processes needed to erect a building is paramount, such simulation should be considered as a set of interlinked models of different construction processes, which would evolve in time based on (partial) data received from sensors.

The level of detail in modeling those construction processes would depends on:

(1) the kind of data from sensors on the field (partially observable system);
(2) the pre-processing and integration among heterogeneous systems of information acquisition, for example, images and temporal series of spatial positions;
(3) the predictability of the productivity of construction workers [9], when they are involved (which is frequently).

Probably, for each set of construction processes, sensor network, and different inputs or variables (work force, equipment, raw materials), one would have to choose a different level of detail in the model for use in the simulation.

The questions addressed by this research are: how to use simulation as a link between 4D BIM models and a network of sensors on-site (off-site)? How to develop such models of construction processes, and how to measure the adequacy of a chosen level of detail for each one?

Until now, there is not a formalization in how to integrate and connect the virtual world of BIM models, and the data gathered in the field. Some research has been done in the development of cyber-physical systems to be that link [10].

In that context, the objective of this preliminary work is to study and validate the level of detail necessary to incorporate one specific type of sensor, an ultrawide band (UWB) localization system, and try to figure out the right amount of detail necessary to capture the movement of work force, materials, and equipment.

The adopted methodology was to create and validate the model in an existent simulation platform to streamline the modelling and analysis of different details of a construction process. There are a few commercial platforms (like Arena, ProModel) that allow the modelling of construction processes. The present work is not focused in exploring the advantages and disadvantages of each one; given its availability, ProModel was the choice.

The focus of the present work is in the activity of structural masonry. A database of manually collected productivity measures was used to setup the parameters of the model, and to create post-processed data from UWB sensor.

2.2 Background

Manufacturing industries, in the context of Industry 4.0 concept, are using simulation not only to optimize shop floor layout, but as a digital twin of the real factory producing its own products. Referred as a cyber-physical system, it is a way to integrate horizontally and vertically one enterprise, to reduce costs and time-to-market, and to increase customization of its products, among other potential benefits.

Simulation for Construction industry is not a widespread application. Some issues with regard to simulation of processes in construction are: (1) difficult to model and to code with a simulation language [11]; (2) ideal models, and results do not agree with practice [9].

In specific construction processes, like in pre-fabrication of building components, simulation, being similar to manufacturing, are better developed [12, 13], because it provides a more controlled environment to predict work progress. Such simulation also counts with processes monitored sensors, like RFID technology [14].

There are also discussions of simulation being represented by dynamic systems [15], or just a logical sequence of actions.

In recent years, discussions involving 4D BIM models, with planned construction work, and real-time monitoring current work on the field, using different sensors started to appear [16]. One interest work [10] advocated the bi-directional link between BIM and sensors for monitoring construction progress using cyber-physical systems.

The framework in which the present work is developed follows some ideas from [7], but try to expand its uses. The simulation approach in this work is focused in the "logical sequence among the operation process or tasks", trying to manage resource's use [9].

2.3 Methodology

Based on manually collected data of productivity on-site for the masonry construction process, two types of simulation were elaborated: a model inside Microsoft Excel spreadsheets (as a tool to decide the right amount of workforce needed for the job), and another model in ProModel.

It was decided to implement the "same model" with a different level of detail inside ProModel system to compare how the difference in information could render different outputs, and how it could help in plan, monitor, and manage construction work. The representation detail was determined having in mind that data from position in real-time of construction work forced would be given by a UWB localization system.

2.4 Proposed Framework for Integration of 4D BIM Models and Sensor Data of Construction Activity Progress

The proposed framework allows virtual models of construction processes to work as the integration between 4D BIM models, or more specifically, certain activities of the work schedule, and data processed from sensors on-site (or off-site).

Considering that:

(1) there will be a model for each construction process, for example, one for foundation work, another for structural masonry, and so on;
(2) the combination of the execution of those models, sometimes in parallel, sometimes in sequence, should provide a real versus planned 4D BIM model;

Petri Nets should be a natural choice as the bi-directional link because there are many formalisms based on it, which allows stochastic transitions, transitions based on the reception of signals (data) from outside the system, and so on.

Figure 2.1 gives an overview of the proposed framework. Productivity measure database could be used to setup parameters of an initial model, and to real-time monitoring construction progress. The latter would be used directly to activate transitions in the Petri Net simulation.

Previous works were done in trying to stablish a methodology to facilitate the elaboration of the virtual construction process. It was addressed in [17], with the proposition to derive a Petri Net discrete-event simulation model from IDM (Information Delivery Manual) in BPMN language (following general mapping proposed by [18]). As professionals from AEC industry are already using BPMN language to specify IDM, to be later used to derive specific Model View Definition (MVD), it could be considered a promising starting point. Also, as a matter of future research, the use of EXPRESS (IFC) as a modular language to specify an object-oriented simulation of construction processes should be considered.

2.5 Case Study: Masonry

The construction work process analyzed in this paper is structural masonry. The simulation presents work in the construction of four tower, where two of them were dealt in parallel work to optimize the use of workforce.

The base parameters used to create the simulation were derived from historic data collected on the field. Some criteria were adopted to create standards for data collection:

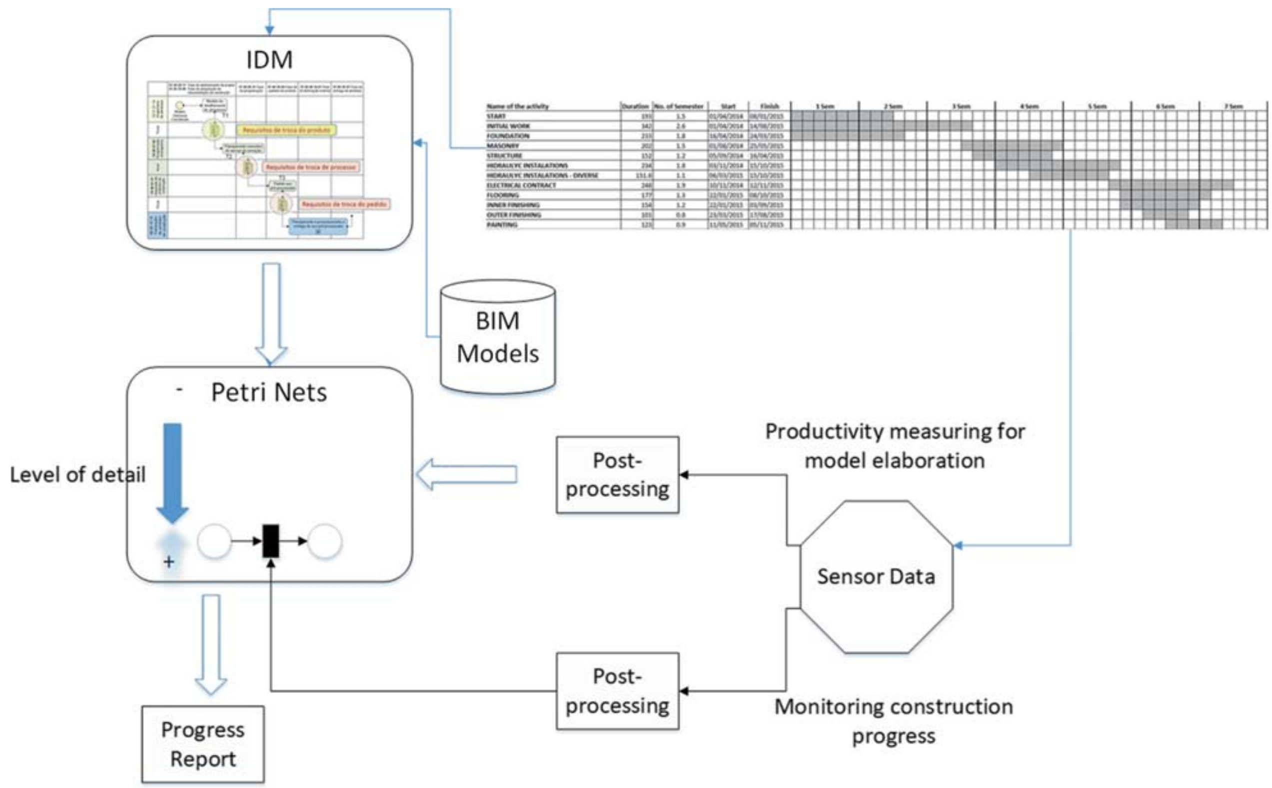

Fig. 2.1 Proposed framework for integration of 4D BIM models and sensor data for automatic construction report

Fig. 2.2 Image from the construction work in which the case study was developed

- In time measurement registration, stop periods smaller than 30 min has been deduct;
- Collecting plans, divided by sectors, were used, considering previously collected quantities;
- The amount of the workforce has been daily collected, identifying only those which were selected explicitly to the work being monitored;

Characterization of the working site: residential buildings for low-income people, 4 towers in total, 8 reference floor plans for each building, 8 apartments by floor and 2 different layout areas: 51 and 62 m^2 (Fig. 2.2).

Fig. 2.3 Skytrack

On each floor, there are 531.12 m^2 of slab area and 889.84 m^2 of structural masonry area, right foot of 2.60 m with 0.010 m of slab thickness (pre-slab) coated by pumped concrete.

Vertical transport had been implanted with Skytrack (Fig. 2.3), for the displacement of bricks and mortars pallets, until sixth floor was reached. A pinion elevator was used for the remaining floors.

Future work will be done in monitoring masonry construction workers on-site with a UWB system. The main objective is to study dimensioning of the work force, and non-added value displacement of resources to increase productivity on-site.

2.5.1 Simulation on Excel Spreadsheets

Based on productivity indicators, a "simulator" was developed and implemented on Microsoft Excel spreadsheets (Fig. 2.4). The quantitative data collected, have been tabulated following the productivity methodology developed by [19] of RUP (Unitary Rate of Production): daily RUP, cumulative RUP and potential RUP.

Based on these indicators, the "simulator" interpolates the most proper RUP for each project and search for the best productivity value. From those values, it identifies quantity and cost of workforce, and quantity of materials by step/floor required to attend the productivity goals (Fig. 2.4).

However, the "simulation" with Excel is restricted to show which resources, and in which place they must be applied, without allowing to deal with organizational and logistical optimization.

In trying to solve these variations, the ProModel, a software for simulation available to the research team, has been used.

2.5.2 ProModel Simulation

ProModel uses concepts such as entities, resources, locations, processing and arrivals, as basic building blocks of its simulation.

Entities are anything that will be processed in the simulation, and resources are agents in the transformation processes of entities. Both will generate, in general, the points looked after for analysis of the modeling details. In this simulation, entities are: raw material that end up being the structural masonry. And resources are the moving machinery and the pallets supplied.

Locations are fixed places which entities pass through: can be the place of arrival, processing or output. In the simulation made, the locations are: stock and sub stocks of supplies, each building tower and pinion elevators.

Processing are the logic of how entities travels from one location to another. Processing in this simulation are: transportation machinery with consideration for loading and unloading wait time, including supplies of pallets to specific building floors.

Arrivals are the moments in which the entities are inputted in some location in specific times of the simulation. In this simulation, the arrivals are: the input of machinery of transportation and the input of pallets of supplies.

	1º DIA			2º DIA			3º DIA			4º DIA			5º DIA		
Horário	7 às 17	17 às 17		7 às 17			7 às 17			7 às 17			7 às 9	9 às 17	
Serviços	Marcação	Elevação		Elevação			Elevação			Elevação			Elevação	1º Graute	
Duração	8.65 h	0.35 h		9.00 h			9.00 h			9.00 h			1.34 h	7.66 h	
Produção	91.07 m^3	7.74 m^3		200.00 m^3			200.00 m^3			200.00 m^3			29.77 m^3		
Produção %	100%	1%		33%			64%			95%			100%	85%	
Profissionais	6 Of	6 Of		6 Of			6 Of			6 Of			6 Of	6 Aj	
Blocos	12 pallets	1 pallets		26 pallets			26 pallets			26 pallets			4 pallets		
Argamassa	53 sacos	4 sacos		116 sacos			116 sacos			116 sacos			17 sacos		
Aço													430 kg		
Graute														7.7 m^3	
Num. Viagens	12 viagens	1 viagens		26 viagens			26 viagens			26 viagens			5 viagens		
Tempo (min)	120 min	10 min		260 min			260 min			260 min			50 min		
Tempo Total	130 min			260 min			260 min			260 min			50 min		

Pavimento Selecionado	6ª

Tipo de Transporte	Cremalheira

Selection of the type of transportation

Tempo min de Espera 2º Graute	6 h

Fig. 2.4 Production programming of the simulator inside Microsoft Excel

2.5.3 Results

In the ProModel simulation, it was possible to represent the site layout, and visualize horizontal and vertical transportation. It is also possible to identify some points that were impossible to identify in the Excel simulator. The programming and visual results of the simulator make it easier to understand many issues related to productive process.

Material stocks have been divided in locations: main (localized behind of tower 3) and temporary (in front of each tower according to productivity schedule). Figure 2.5 shows the construction site, and the horizontal transport logistic (the dashed line), which has been done by two Bobcats.

The ProModel simulation showed that, even with full capacity of all available equipment to produce, it would never reach the goals pre-established due to restrictions of layout and poorly studied choice of equipment. The test provided the perception that the equipment had a significant idle capability; however, it would not be possible to use it more often due to layout issues. For example, the Skytrack blocked a big area to be operated, thus paralyzing the zone around it (Fig. 2.3). It is possible to see the rear of the equipment during the movement to lift the pallets, blocking the access to any other equipment. In other words, while the material is lifted, it becomes impossible to do the horizontal transport of another material and vice versa.

Once identified the Skytrack problem using the ProModel simulation, it became possible to try other options to do the vertical transport. The solution tested has been to implement the pinion elevator, due to its load capability, cycle time and costs.

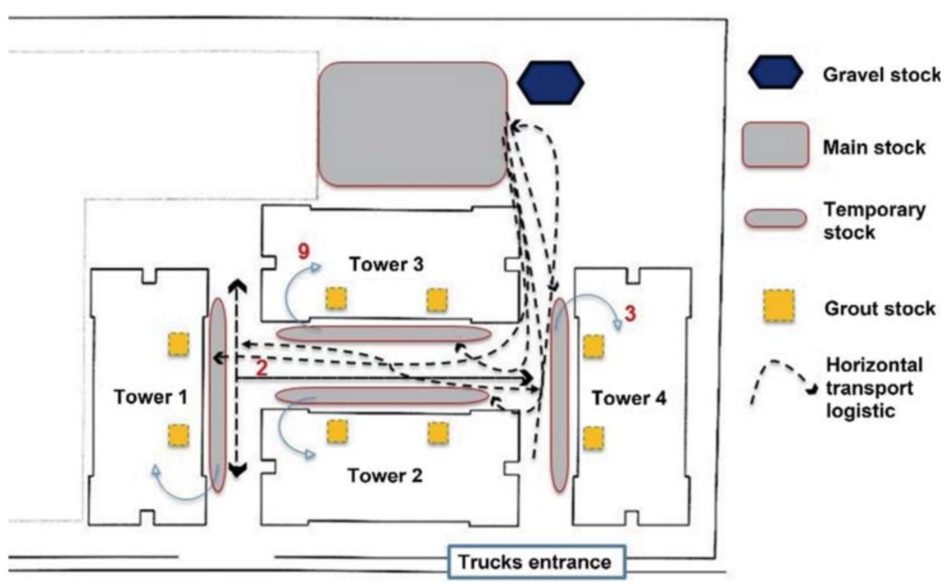

Fig. 2.5 On-site layout

Although it is a major investment (compared to the Skytrack), it produces better results to attend the production demand, and it would result in lower cost of the idle workforce, production delays, etc. Through the simulation, it is possible to identify these points, what brings the idea that there are many ways to predict a lot of Improvements and implement solutions on a short period of time.

Also, it is possible to see that between towers 3 and 4, there is a significant material flux, which afterwards has been identified as one of the logistic bottlenecks.

Some trials were also done in modeling with more detail each building tower. In these tests, the representation of each wall in each pavement was considered, as the localization system (UWB) could give the exact location of each individual of the workforce personnel. The main problem with this approach is that the order inputted in the simulation of work in each wall could not be predicted as decision still are made on site, of where to begin work of the present day.

2.6 Conclusions

In the context of evaluating construction processes simulation as a link between 4D BIM models, and data automatically collected on-site, primarily for automatic report of construction progress, two different initiatives were tested: an Excel spreadsheet, and a ProModel simulation. For the latter, different levels of details were trialed to adequate the model to future data collection situation in which workforce personnel will be tracked by a UWB system.

Results obtained from ProModel simulation (the potential of its use) were compared to a Excel spreadsheet simulation (worksheet calculus automation for the dimensioning of the workforce). Based on results of the simulations, it was possible to see a large improvement potential in using ProModel simulation when compared to traditional productivity system analysis. However, it is still necessary to develop strategies to information collection in real time (by means of sensors) to the promote corrective actions and strategy changes (through productivity failure) so it could be applied in a shorter period of time.

Although the ProModel choice has been linked to software availability, just a simple simulation result exposed problems that, in real life, were only realized after months of production as the cause of inefficiency in the workforce.

The amount of detail initially considered did not represented on-site layout and the movement of the workforce personnel (Excel). The initial model was further detailed to expose a rough movement of people in specific pavement, so it could be correlated to the data acquired by the UWB sensor system (ProModel). With the implementation of UWB system, it is expected the collection of real time of the flow of materials and people, the spent time on each workplace and with this every necessary information to the productivity simulation in real time.

However, the proposed implementation in ProModel does not allow to further development of a practical link with BIM models and construction progress on-site. Parallel work is being done in the simulation based on Petri Nets, which are largely used in the elaboration of controllers and the incorporation of observation of states of the system. To cope with conditions on-site such as weather, equipment fail, and so on, the use of stochastic transitions and transitions activated by external signals (from sensor on the field) are being incorporated in the model. Considerations are being made to provide choices made onsite by the workforce (for example, which wall to build first, each day) as a stochastic processes inside a new platform of simulation (Petri Nets), and to obtain through sensing, which walls are being constructed in real-time.

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