Industrialization of site operations planning and management: a BIM-based decision support system

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Abstract. Construction industry faces many challenges as socio-economical needs evolve and Building Information Modeling (BIM) disrupts practices. BIM processes and solutions are mainly suited for the design stage of a project and experts are currently working to bridge the gap with the construction stage. Improving on BIM practices could be done by creating a more industrialized way of handling construction operations by learning from other industrial fields. This could help to manage quality, delay, and cost more precisely, while considering new indicators (e.g.: GHG emissions). BIM could be improved by developing a construction stage specific data structure inspired by Product Lifecycle Management (PLM) systems. This requires to dynamically manage data for different stakeholders before and during the operations. This paper presents a conceptual data framework to develop a BIM-based decision support system to plan and manage construction operations. A 4D digital mock-up is gradually enriched to support construction processes studies resulting in a *As Planned* view of the building. Process engineering work is carried through iterative loops and supported by knowledge-based indicators. A cross-disciplinary workflow allows the use of new production methods (e.g.: off-site modular construction). An *As Built* view of the mock-up is concurrently created as operations advance and changes occur, feeding back the knowledge-based indicators.

Keywords: Building Information Modelling, Product Lifecycle Management, Knowledge-Based Engineering, Enterprise Information System

1 Introduction

The Architecture, Engineering, and Construction (AEC) industry is transforming its ways to adapt to contemporary needs. Professionals must balance the management of costs, time, and quality with news demands, e.g.: evolving standards, sustainable development [1, 2]. Changes are needed in designing and constructing buildings. This could be done by industrializing the production of buildings. Industrialized construction can be defined by new building methods, e.g.: off-site modular construction [3], and by precisely managing a project information during a building lifecycle [4, 5].

Industrializing the construction stage of a building project can be done by tackling site management activities. The core activities of site management are operations planning and monitoring, both rely on an interdisciplinary workflow involving process engineering practices, budget management, resources management i.e.: workers, machines and tools, materials, and sub-systems. Combining those, we can describe a site or a building under construction through operations workflows or the flows of resources in and around a site [6]. This gives a product-process-resources (PPR) point of view of the work [7].

Building Information Modeling (BIM) is at the center of this transformation as it helps professionals managing information and improves productivity [8]. Manufacturing industry practices is a source of inspiration to develop knowledge management practices for AEC projects. Manufacturing information management practices are centered around the holistic concept of Product Lifecycle Management (PLM) [9]. Learning from PLM could improve BIM practices [10]. A first step to industrialize building production could be made by combining a PLM-based data management approach with site management BIM applications [11].

This paper presents a first approach to define a knowledge-based decision support system for site operations management. We focus on site planning and monitoring activities with a BIM-based and product-process-resource-oriented workflow. We investigate what are the main components of an industrialized site management information system from a functional, roles, and data point of views.

In section 2 we present the scientific background relevant for this work. In section 3 we present the *As-Is* system and detail the information system *To Be* by defining its key components. Conclusions and future work are discussed in section 4.

2 Scientific background

2.1 Challenges in structuring information for site operations management

Construction sites are complex production systems [12]. Operation scheduling and monitoring are important tasks to make sure everything is done right. Site management often rely on basic tools: Gantt charts, spreadsheets, and 2D drawings. These tools and their uses have not changed significantly in the last 30 years [13, 14]. Site management methods and digital tools are being developed to improve productivity. Digital solution focus primarily on linking a digital mock-up (DMU) with a project schedule, creating a 4D BIM process [15]. The main challenge is to account for the recurring changes that occur on the construction site, and the data visualization depending on stakeholders' point of view [16, 17]. Commercial solutions are emerging but their adoption rate remains low [15]. BIM is seen as a new way to deal with construction operations while integrating a PPR point-of-view [18]. Adapting BIM practices to the site management means to develop a digital thread between the design and construction stages, and new workflows to account for the new information management capabilities [5, 12]. This information management approach is known as Building Lifecycle Management [4]. It draws from the Product Lifecycle Management approach developed in the manufacturing industry [19]. In [20] we detail our views on why and how to leverage a PLM-inspired approach to improve on BIM practices for site management, and how to account for 4D BIM capabilities. This would improve managing projects that are becoming more complex from a technical, digital, and organizational point-of-view [21].

3 Methodological framework for an information system supporting site operations management

BIM and site management practices could be improved by developing a greater industrial working approach. This can be achieved by developing a knowledge-based information system for site management activities. In [20] we presented a first draft of a BIM-based decision support system that could help professionals to plan and monitor site operations. In this section we define and detail how this system could be frame. It is built around a process engineering BIM mock-up that is connected to other enterprise information systems.

3.1 As-Is organization

Planning and managing construction operations are complex activities involving many stakeholders. Before operations starts, planning work is mainly done by process engineers. Their work focuses on analyzing the feasibility of a project and devising processes that account for technical and financial constraints. This work generally depends on the engineers' experiences. Process engineers cooperate with other professionals to plan construction operations. The general foreman and site foreman play a key role in defining processes. They review deliverables and provide feedback on technical solutions and on-site context, e.g., site logistic constraints, workers expertise, sub-contractors skills. Equipment manager and purchaser also help optimizing construction work by allocating and buying the needed materials, machines, tools, and subcontracted services, and human resources manager dispatch workers. The general foreman activities currently represent a choke point to manage engineering and construction activities [20]. A new work organization is needed.

3.2 Developing a new information system

Framing the system functions

Enterprise information systems (EIS) are complex organizations defined by their social, technical, and economical dimensions [22]. Creating a new EIS implies to structure a new work dynamic with different shared responsibilities to use properly it. Doing so means to define the constitutive elements of the system and their relations from different points-of-view [23]. Several methodologies and tools exist to define and build an EIS, e.g., The Open Group Architecture Framework (TOGAF) [24], the GRAI methodology [25], or the Zachman framework (ZF) [26]. We choose the ZF because it is recognized as a *de facto* standard [27], and is practical enough to be used for a research study.

The ZF is based on a 6x7 matrix: columns represent the basic questions of engineering work, and lines represent the concretization of the work according to a specific point-of-view. Each box must consider the content of the ones on its sides and above and below to create a systemic picture of the enterprise and its EIS. Each box then represents a primary component of the EIS [27].

In table 1 we detail our comprehension of the system to be developed according to the ZF. We choose to focus on few boxes that represent the core description of the system. Boxes are defined through iteratives interviews of experts. Three boxes are refined using diagrams to improve comprehension in figures 1, 2, and table 2.

Lines are originally titled with names associated with AEC actors [28]. We changed them to avoid misinterpretation because this research work is conducted within a construction company. The new names seek to reflect the point-of-view of the EIS they represent.

Table 1. Zachman framework of the system to be

	Why	When	Who	How	What	Where
Strategic				Profoundly change working practices		
Operational	Improve productivity. Efficiently use resources. Reduce carbon footprint.	Project lifecycle		Capitalize on engineering knowledge. Strengthen expertises. Transform design and construction activities.		
Fucntional			Strengthen engineering practices. Site management team focuses on production. Minimize design activities during construction stage.			
Technological			See figure 1	See figure 2		
Technical					See table 2	

Strategic – How

The experts we interviewed concur that AEC work practices must change to tackle the many challenges facing the AEC industry. This can only be done by profoundly reshaping working practices within the company and changing how the industrial ecosystem operates.

Operational - Why

Changes are motivated by a will to improve the industry productivity while developing sustainable ways to build and use resources. Companies must adapt to climate change and economic change, while remaining cost-effective.

Operational - When

Changes of practices must occur on the entire lifecycle of a construction project. Companies must reorganize themselves to build differently.

Operational - How

Managing engineering knowledge can leverage new building practices and help to better manage complex engineering projects.

Functional - Who

Knowledge management practices should help to improve existing working practices and developing new ones. Site management activities must be reshaped to focus solely on production management. Design activities are to be managed independently and construction can start when the building design is considered mature enough and less prone to changes .

Defining the system's work organization

Technological - Who

In figure 1 we suggest a new work division across the lifecycle of an AEC project so to avoid choking point. Boxes represent major AEC activities. We numbered the activities to better understand the work sequence from start (#1) to finish (#6). A project lifecycle starts with the design of the building. We suggest creating a new role with the engineering manager who should coordinate and manage technical analysis for the project in and out of the construction company. Once the design is set, process engineer can plan site activities. The engineering manager and process engineer team up to optimize the building from a design and construction point-of-view. Materials, machines, tools, and sub-systems can be bought or allocated from the company resources stocks, during processes development while working forces can be dispatched or sub-contracted. We suggest creating the role of logistic coordinator to manage physical resources just as a HR manager dispatch workers between sites. The logistic coordinator interacts with the general foreman to adapt the allocation of resources to the site as operations develop. With this work division, the general foreman and site foreman can focus entirely on managing construction operations. When construction operations are finished, the building is handed over to the client.

Defining the system's basic data architecture.

Technological - How

The work division suggested in figure 1 helps us to define the major functions of our EIS. Figure 2 represents a functional architecture view of the system to be. This representation is not based on any standard for information architecture. Blue boxes represent the main functions. They are numbered in the same order as the activities in figure 1. White boxes represent sub-functions of each main function.

Work is centered around the DMU of the project. Specialized views of the DMU are gradually developed for specific activities. Information managed in the DMU are exchanged with other information systems when needed to carry-out specific functions. Engineer manager develops an *As Designed* view at the beginning of the project. It serves as a basis to develop a preliminary planning of the project. When design activities are finished, process engineer develop an *As Planned* view and a precise master planning of construction activities. Engineers optimize the project as they develop their solution through iteration cycles. Thanks to the quantity take-off (QTO) obtained, resources can be acquired and dispatched to prepare operations. Data from the *As Planned* DMU are exchanged with the Enterprise Resource Planning (ERP) and the central purchasing service. When operations start the general foreman and site foreman develop the *As Built* view of the DMU and compare it to the *As Planned* view. Depending on the operations development, resources and workers dispatching can be adapted and the *As Planned* view can be reconfigured to take into account new and up to date parameters, e.g.: delivery period, lifecycle assessment indicators, change orders. When operations are over, the building is handed over to the client, and the project information are archived for legal and contractual purposes, and for knowledge management purpose. We add a change management function to the system to control data evolution through the entire project lifecycle.

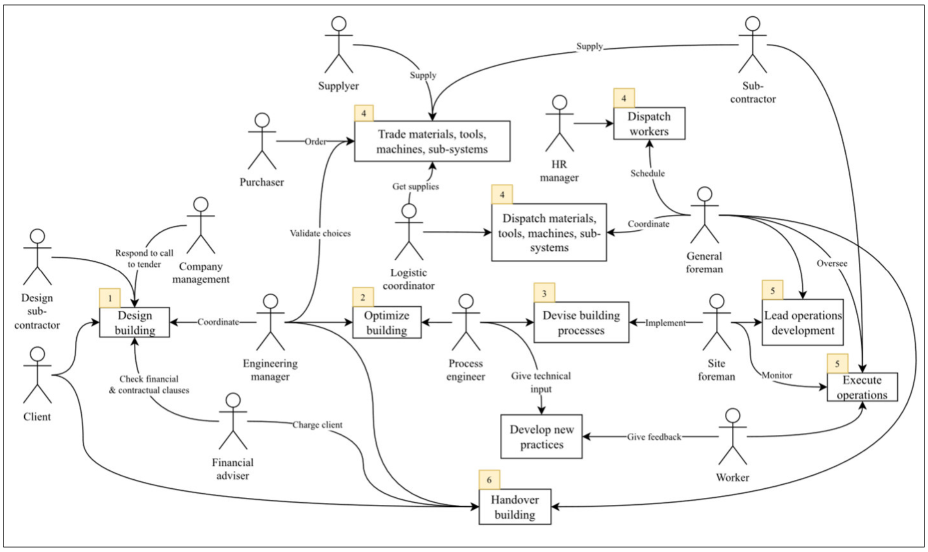

Fig. 1. Operation planning and monitoring tasks organization of the system *to be*

Technical – What

To further detail our understanding of this system. We present in table 2 an example of the type of data to be used as a work basis. We also mention their possible interactions with other information system or data bases. We detail the data needed by the function *Devise building processes* as it is a central point of the system. Each sub-function can be associated with a technological solution. We then list the type of data needed by each function. For example, QTO are obtained by managing the geometric data of the *As Planned* DMU. We define operating condition based on the QTO, the associated time ratio for each type of element, and the tools and machines needed to execute building operations. The detailed planning can be linked with the HR information system or the central purchasing system to assess the resources available for the project.

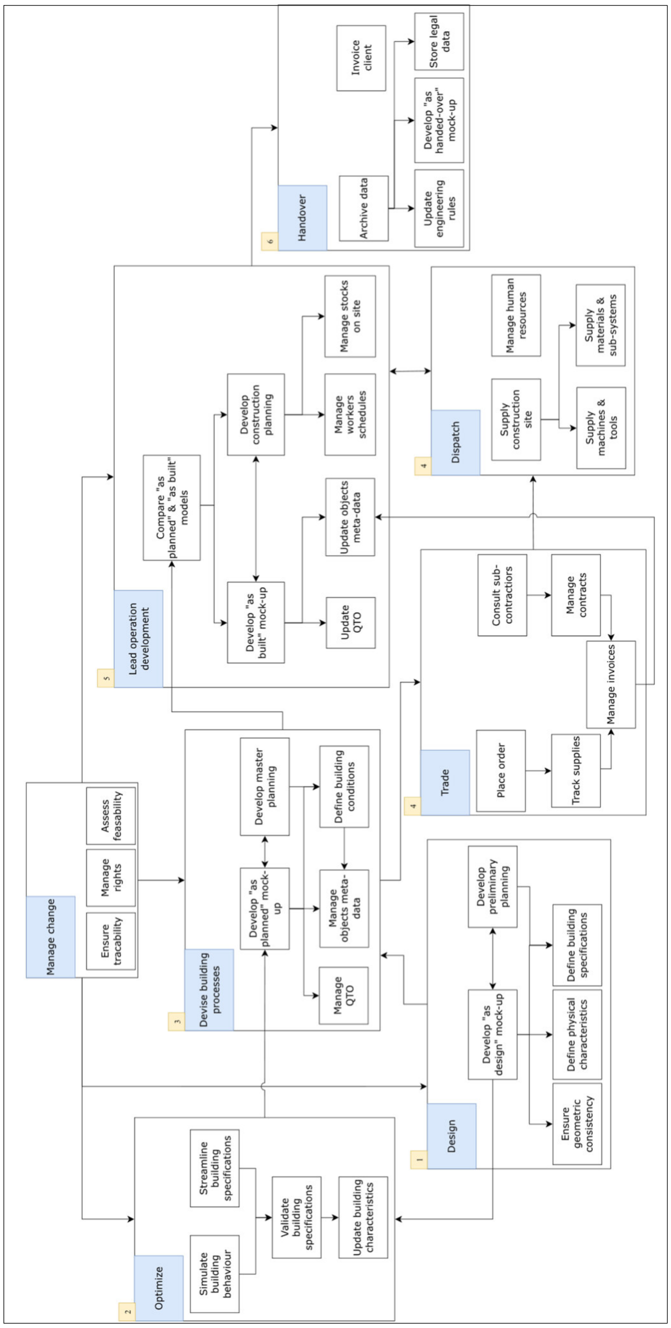

Fig. 2. Operation planning and monitoring functional architecture of the system to be

Table 2. Example of data typology for the system to be

<table>
<tr><td>Function</td><td colspan="4">Devise building processes</td></tr>
<tr><td>Sub-function</td><td colspan="2">Develop as planned mock-up</td><td colspan="2">Develop master planning</td></tr>
<tr><td>Technological solution</td><td colspan="2">4D BIM model</td><td colspan="2">Planning solution
(e.g., Gantt chart)</td></tr>
<tr><td rowspan="2">Data</td><td>Manage QTO</td><td>– Objects geometry</td><td rowspan="2">Define operating conditions</td><td rowspan="2">– Time ratios
– Activities sequences
– Version
– Link with QTO
– Link with HR system
– Link with logistic data base
– Link with central purchase service</td></tr>
<tr><td>Manage objects meta-data</td><td>– Physical properties
– Version
– Lifecycle Assessment
– Link with planning
– Link with central purchase service</td></tr>
</table>

4 Conclusion and future work

The architecture, engineering, and construction industry is in need of changes. Projects are becoming more complex, and new demands must be met. To adapt, construction companies are industrializing their work practices, notably site management activities. Industrialization can be achieved by combining a project digital mock-up to other information systems. This paper presented a conceptual framework of an information system for planning and monitoring of site operations. We identified the core functions of the system. We presented a new enterprise architecture to leverage this system. We also presented a functional architecture of the system and the main types of data to be managed by the system.

This work is part of a greater research project. We intend to investigate further the composition of the system we introduced by precisely identifying the data needed by the system and how they interact to process a given function, or defining performance indicators to support decision making. We ambition to test it on a life-size use-case with our industrial partner.

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