# Digital solution for planning and management of construction site operations: a proposal of BIM-based software architecture and methodology

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Félix Blampain[1-2], Matthieu Bricogne[1], Benoît Eynard[1], Céline Bricogne[2], Sébastien Pinon[2]

[1] Université de technologie de Compiègne, Laboratoire Roberval, CS60319, 60203 Compiègne Cedex
{felix.blampain, matthieu.bricogne, benoit.eynard}@utc.fr
[2] Spie batignolles, 92000 Nanterre
https://www.spiebatignolles.fr/

**Résumé** : L'industrie de la construction subit plusieurs changements en raison des évolution des contextes socio-techniques et des bouleversements dans la gestion de projet induit par le BIM. Les usages du BIM sont principalement limités à la phase de conception et il est nécessaire de les déployer sur la phase d'exécution. Cela demande de gérer des données hétérogènes de manière dynamique pour accompagner la gestion des activité de chantier. Cet article présente une proposition conceptuelle d'un système d'information d'aide à la décision pour aider aux activités de planification. Une maquette BIM 4D sert de base de travail pour proposer des méthodes et processus constructifs. Les ingénieurs conçoivent ces proposition à l'aide d'indicateurs basés sur des connaissances métier, au travers d'une organisation coopérative du travail. Plusieurs modèles du systèmes et une méthodologie de travail sont présentés.

**Mots-clés** : Building Information Modelling, Product Lifecycle Management, Système d'Information d'Entreprise, Gestion de la Connaissance

**Abstract** : The construction industry is undergoing different changes as socio-technical contexts evolve and BIM is disrupting how to manage a project. BIM uses are mostly limited to the design phase and there is a need to deploy BIM on the construction phase. This requires managing heterogenous data dynamically to support site management operations. This paper presents a conceptual suggestion to create a decision support information system to help planning activities. A 4D digital mock-up serves as a work base to suggest construction method and processes. Engineers design these suggestions thanks to different knowledge-based indicators through a cooperative workflow. Several models of the system and a work methodology are presented.

**Key-words** : Building Information Modelling, Product Lifecycle Management, Enterprise Information System, Knowledge Management

## 1 Introduction

The construction industry changes as new processes, methods, and tools are developed. Building Information Modelling (BIM) is at the centre of these changes since digital applications are transforming how to design, manage, and monitor a construction project. This digital transformation is comparable to what happened in the manufacturing fields in the 1990s with the advent of Product Lifecycle Management (PLM) (Boton et al., 2018). Nowadays, manufacturing and construction industries are shifting towards data-centred engineering practices to tackle industry 4.0 issues (Meski et al., 2019; Zhang et al., 2022). Contrary to PLM,

BIM is not fully deployed on the entire lifecycle of a building, and there is a gap between the design phase and construction phase (Bolshakova et al., 2018). PLM can inspire BIM development (Aram & Eastman, 2013) and notably BIM applications for site operations management (Jupp, 2013). This digital shift generates lots of data that are seen as a new resource for companies. Managing them is becoming an important task which forces companies to develop dedicated infrastructures and methods (Lapalme et al., 2016). This gives rise to knowledge management practices (Assouroko et al., 2014).

This paper presents a conceptual proposition for a knowledge-based decision support system dedicated to site operation management. It supports process-engineering practices that study how to implement building parts, produce construction schemes, and chose the resources needed. We develop this system with a product-process-resource perspective stemming from a PLM and BIM point-of-view.

The first section presents a state-of-the-art review of PLM and BIM interaction, BIM practices for site operation management, and new production practices derived from the manufacturing fields that can rely on a PLM and knowledge-based approach. The second section present the research issue. The third section present the conceptual details of the system we propose. The final section concludes by presenting future work that will follow this paper.


## 2    State of the art


### 2.1    PLM as an inspiration for BIM development and implementation

BIM can be a leverage to face the challenges currently disrupting the construction industry. It represents a technological shift from typical practices as it changes the way professionals organise themselves to design, build, and operate a building. BIM needs to be deployed throughout the lifecycle of a structure to be fully effective (Sacks et al., 2018). The main challenge is how to deal with data and information usually associated with technical documentation. BIM development can draw inspiration from other industrial fields which are facing similar issues. Manufacturing sectors created Product Lifecycle Management (PLM) starting from the 1990s to manage a product technical data (Saaksvuori & Immonen, 2008). Nowadays, PLM is defined as holistic business strategy to manage jointly a product and its documentation during their entire lifecycle (Terzi et al., 2010). PLM can be a source of inspiration to develop BIM (Aram & Eastman, 2013) but no consensus has been reached on how to do so (Mangialardi et al., 2017). Drawing on PLM practices could result in a master plan to apply BIM practices from the beginning to the end of life of a building, resulting in a dedicated strategy called Building Lifecycle Management (Bricogne et al., 2011; Mangialardi et al., 2017).

#### 2.1.1    Data management

A BIM digital mock-up is object-oriented, meaning that a building is represented by its elementary components and their associated data (Sacks et al., 2018). These components can be classified according to different formats serving one or several purposes (Boton et al., 2018). The most common format is Industry Foundation Classes (IFC) which can cover most of a building lifecycle and was developed to ease file exchange (Mendes de Farias et al., 2018; Vanlande et al., 2008). Every classification format relies on the same principle: elementary components are grouped into families and sub-groups, and their level of development (LOD) vary according to the lifecycle stage. Components can also be defined by their relationships: e.g. windows are inside a wall. The classification obtained is called a Product Breakdown Structure (PBS) (Boton et al., 2018).

PBS are comparable to bill-of-materials (BOM) used in PLM applications to describe a product. BOM list the elementary components, and their quantities, of a product at a specific

lifecycle stage: e.g. engineering BOM (eBOM) and manufacturing BOM (mBOM) are respectively the "as designed" and "as planned" description of a product (Pinquié et al., 2015). The sum of all BOM makes a Product Structure (PS). Each component in the PS is defined by its relations to the others, its data, and metadata. All this information gives a more dynamic and global view of the product, compared to the PBS which only shows a fixed hierarchical description of a building (Boton et al., 2016).

PBS could be improved by manipulating more precisely IFC data to develop a product description similar to a PS. Professionals can currently exchange parts of IFC files representing task-related views of a building: e.g. structural-view or plumbing-view for design applications. These views, called model views, filter the whole model to show the needed data, and are defined by a Model View Definition (MVD) (Sacks et al., 2018). Sets of model views could be compared to sets of BOM. Yet, model views management is tedious as a new file needs to be created for every model update and there is no link between the IFC files of a project (Beetz et al., 2009; Mendes de Farias et al., 2018). Model view management and IFC management can be improved by managing their data with semantic web technologies (Beetz et al., 2009; Sacks et al., 2018). Thanks to this approach, users switch from a file-centred management to a data-centred management of the project as only one file is needed to deal with BIM data and model views can be extracted and updated from this unique file (Beetz et al., 2009). This data management approach also allows to easily develop new BIM objects to better represent the building and new types of interfaces with information systems which is lacking in the present IFC data structure: e.g. construction machineries or Enterprise Resource Planning (Ruiz-Zafra et al., 2022).

Improving a project data flow would improve processes and communication between stakeholders. Data exchange need structuring like any other activities but there is no consensus on how to standardise this process. Stakeholders have different requirements concerning data management which could impact the overall project management. Data structuring and data exchange have to be integrated into requirement engineering practices to ensure a common ground for work.

### 2.1.2 Requirement management as a framework for data management

There is no effective way to link a digital mock-up (DMU) with the project requirements (Bérard & Boton, 2018). This hinders the project management since managing the mock-up LOD is a difficult task. The difficulty origin could be threefold: (1) project requirements definition lacks formalism (Mauger, 2014), (2) BIM uses definition lacks consensus among stakeholders (Jupp, 2013), (3) design and technical agreements are cumbersome to reach (Bensahaila et al., 2021; Motamedi et al., 2018). Requirements management could benefit from a PS-management approach as requirements and their LODs could be managed like elementary components of a project. Doing so would improve the data continuum of the DMU during its lifecycle (Assouroko et al., 2014; Bosch-Mauchand et al., 2013). Stakeholders need a cross-functional cooperation to ensure a joint management of the requirements and the DMU. This can be done by developing a process-centred and a data-centred point of view of the project (Aram & Eastman, 2013; Eynard et al., 2004; Jarratt et al., 2011).

Requirements are a key part to frame project management practices, drive design choices, and restructure construction activities within a BIM strategy. The lack of consensus on BIM uses could also be attributed to the uniqueness of the product (Boton et al., 2018). Stakeholders adapt to this difficulty by relying on their experience. They put their knowledge to use on new project to design dedicated solutions. Working group knowledge could be recorded and reuse from one activity to another to create a working base for everyone. Retrospect studies of the DMUs or project documents could inform how to act in context similar from one project to another.

### 2.1.3 Knowledge management as a key building block of enterprise information system

Project complexity and technical constraints are increasing as standards are evolving and clients are creating new types of demands. To face these challenges companies are developing knowledge management skills to better grasp their processes and to create products with added-value (Bosch-Mauchand et al., 2013). Knowledge management relies on recording, sharing, and reusing data and documentation from one task to another (Assouroko et al., 2014). This can be done by linking enterprise information system together with a PLM application and by organising stakeholders and workflow accordingly to support this strategy (Bosch-Mauchand et al., 2013). Mapping and structuring data and work processes falls into the enterprise architecture field of study which focus on understanding the behaviour of socio-technical organisations (Lapalme et al., 2016). This discipline also studies enterprise information systems (e.g.: ERP, PLM) to develop applications suited to industrials contexts, deal with information integration between all systems, and organise human-in-the-loop interactions in this knowledge management strategy (Romero & Vernadat, 2016). From a conceptual point-of-view, an enterprise information system (EIS) can also be described as a socio-technical organisation composed of physical components (e.g.: people, hardware, etc.), processes (e.g.: workflow, planning, etc.), and information (i.e.: data processed by the physical components). From a technical point-of-view an EIS is a group of softwares organised to support and manage one or several processes (e.g.: supply chain, human resources, accounting, etc.) (Rashid et al., 2002).

One of the most famous models of enterprise architecture is the Zachman framework, defined as an "enterprise ontology" (Lapalme et al., 2016). This framework is also used to develop enterprise information system as it helps to describe a socio-technical system and its processes from different points of view (e.g.: business management, technician, etc.) and according to structuring questions (e.g.: how, when, etc.) that support any engineering work. Points-of-views and questions are combined to model specific views and features of the system. Analysing the models altogether give a theorical complete view of the system (Lapalme et al., 2016).

Historically, EIS are dedicated to product information management, resources management, and quality management. Now, as several EIS coexist and deal with different activities there is a need to interface them to create a digital thread. Doing so would support workflow management between all services of a company and between collaborating companies, as well as data management throughout a project lifecycle. It would also help develop industry 4.0 applications based on digital interactions (Romero & Vernadat, 2016).

Knowledge management practices could be combined with BIM practices to develop new workflow, design solution, and production activities. Stakeholders are gradually considering data, information, and knowledge as new resources to exploit. Putting them to use could improve BIM practices. From this improved BIM practice stakeholders can reshape other engineering activities and deploy BIM further on a building lifecycle.

## 2.2 4D BIM and site management

### 2.2.1 What is 4D BIM?

Planning is an important activity to ensure a smooth-running construction phase. So is progress monitoring. Many management methods exist but are being criticized for many reasons and are reaching their limits (Sriprasert & Dawood, 2002). BIM could be a way to reshape site operation management. Management techniques need to be reshaped around this new approach, from a site management point-of-view and from a global project management point-of-view (Bensahaila et al., 2021; Koskela, 2000).

BIM uses are categorised in different groups named "dimensions" and noted nD. 3D BIM is the visual rendering of the DMU, 4D is the time management of the structure under construction, 5D is the cost estimating of the structure, 6D is the lifecycle assessment of the

structure, and 7D is the overall facility management. Dimensions can be considered separately but each new dimension supposedly includes the previous ranks into itself (Sacks et al., 2018). In the present paper, we focus on 4D BIM as it is the basis of the research issue. Other dimensions will be considered in future work under development.

### 2.2.2 4D BIM present and future trends

A 4D DMU is created by linking the 3D view of the building with a temporal view (Sacks et al., 2018). Contractors have to manage the LOD of the 3D DMU and the LOD of the schedule, both being decoupled (Boton et al., 2015). The goal is to separate operation management and optimisation from the sole workers' experiences. Many uses of 4D BIM have been identified and described in literature. They mostly focus on predictive analysis because it is the main shortcoming of classical management methods (Guerriero et al., 2017; Sacks et al., 2018). These uses require a different workflow and more cooperation between stakeholders to be fully effective (Dashti et al., 2021).

A typical 4D BIM DMU represents a structure in a unique way, but depending on the stakeholder, the activities or the building part, the information needed is not the same and should not be presented in the same way (Isaac & Shimanovich, 2021). Researchers are currently working on this limiting factor. A product-processes-resources point of view is developed to dynamically create specific views of the DMU (Dashti et al., 2021; Isaac & Shimanovich, 2021). The DMU becomes a simulation tool that helps site managers in their work and prepare for activities sequences and anticipate hazards (Dashti et al., 2021).

4D BIM applications are currently limited to the academic world. For diverse reasons professionals have not implemented this technology in their practices (Bolshakova et al., 2018). To be more interesting to professionals, a 4D BIM DMU should incorporate more heterogeneous data and meta-data about construction activities (Bolshakova et al., 2018 ; Mäki & Kerosuo, 2015). This data management can be reshaped by going beyond a BIM approach and drawing inspiration from other project management practices such as model-based project management (Whyte et al., 2016). The goal is again to manage and present data in specific views dedicated to tasks and processes.

With 4D BIM applications professionals have the opportunity to transform site management activities. This would, in turn, impact project management activities in the beginning of life of the building. Changing management processes is a way to modify building practices. Another way would be to modify how building parts are designed and produced thanks to a dedicated BIM strategy and new production systems.

## 2.3 Process-engineering and planning of construction operations

### 2.3.3 Changing the means of production

New construction methods are getting interest nowadays. Some rely on existing technology while others use new types of machines. All focus on producing sub-parts of a building that are later assembled to build the whole building. A first technique consists in assembling sub-system of a building (e.g.: HVAC, structure, etc.) (Li et al., 2010). Another technique consists in producing entire room of a building, called module, which are put in place like LEGO blocks (Wuni & Shen, 2020). A last approach consists in 3D printing pieces of the building by using diverse materials to create structural, technical or architectural pieces (Paolini et al., 2019). Through all these techniques a building can be seen as a kit to assemble which give designers and contractors the opportunity to rethink how each system can be designed and produce (Li et al., 2010; O'Connor et al., 2014). Contractors can choose to combine these approaches with traditional methods to build a product. Inspiration can also be drawn from the manufacturing industry do develop assembly lines or use robots to help workers in their tasks (Anane et al., 2022).

### 2.3.4 Reshaping site operation and the production line

The construction industry has seen little change in its practices in the last 20 to 30 years: construction methods and project management practices have not evolved significantly (Koskela, 2000; Sriprasert & Dawood, 2002) which impacts the overall productivity of the industry. Compared to other industrial fields, the construction productivity is slower (Eastman & Sacks, 2008). There is a need to rethink how to produce a building and how to manage construction operations. This is also an opportunity to tackle other typical issues of construction site. Two major concerns of site management are workers safety and waste management (Goodier & Gibb, 2007; Jaillon et al., 2009). A solution to these issues could be off-site construction. Transferring some activities in a controlled environment like a workshop ease the implementation of quality and security measures while improving resources management (Hsieh, 1997; Won & Cheng, 2017).

Off-site activities cannot be managed like on-site activities. Design, procurement, and construction processes need to be remodelled to support the new supply chain organisation and the project management practices (Li et al., 2010). These new processes and organisation can draw inspiration from manufacturing methods, and be developed and implemented thanks to a BIM strategy (Banihashemi et al., 2018).

### 2.3.5 Reshaping project management

Off-site practices force contractor companies to organise their work differently to manage production sequences, supply chain and effectively link off-site and on-site work. Issues arising during construction phase are often linked to design problems and information loss. A BIM-based design strategy can then be created to tackle construction issues early on (Jaillon & Poon, 2014). Many design strategies exist and rely on a multi-disciplinary organisation to account for every stakeholder needs (Demoly et al., 2011). Digital mock-up are key elements to anticipate issues of productions because they are the common ground for exchanging information and communicating between stakeholders (Bricogne et al., 2015; Demoly et al., 2011).

Producing building parts in a workshop and assembling them on-site changes the typical supply chain of a construction site, and thus its management strategy. Critical success factors have been identified in literature (O'Connor et al., 2014; Shang et al., 2020; Wuni & Shen, 2020). Production must be planned with a product-process-resource perspective from the design stage to account for production constraints such as machining limitation or procurement time. Stakeholder must settle earlier for a solution to ensure a smooth change management process from design to production (O'Connor et al., 2014). A dedicated project management strategy must be implemented to organise the workflow (Shang et al., 2020).


## 3 Research issue

We showed in the state-of-the-art section that the construction industry is undergoing different transformations at once. BIM solutions, practices, and processes reshape how professionals manage and produce a building. There are still challenges, however when implementing BIM for site management activities. Engineering and project management practices realign themselves towards process- and data-centred activities, and companies develop knowledge management strategies to face new industrial challenges. There is an opportunity to develop knowledge-based BIM applications for planning and management of site operations to help professionals with their work, while also providing insights for creating new building solutions.

The present paper is part of a larger research work to study BIM application for site operations. Here we focus on describing a methodology proposal which will be developed in future works. The work is structured around the following research question: how can we suggest a solution for construction planning by managing a 4D BIM DMU and enterprise

knowledge? We define construction planning as scheduling and sequencing site activities in space and time with a product-process-resources point-of-view, while taking into account other indicators, e.g. safety standards, budget, or environmental impacts (Sacks et al., 2018).

We suggest creating an information system, as defined by Lapalme et al. (2016), to put in coherence a project information and an enterprise knowledge. The result would be decision support system to help building contractors to engineer their planning activities.

## 4    Research methodology

We follow the development approach suggested by Romero & Vernadat (2016) to model business processes and implement an enterprise information system: (1) study the business context and define the function of the system; (2) model the business processes revolving around the system; (3) conduct a detailed functional analysis of the system; (4) develop the system using an object-oriented language.

In step (1) we put in coherence the business context with the state-of-the-art review developed in the present paper and in (Blampain et al., 2022). This work is conducted jointly with the French general contractor Spie batignolles which provides first hand business data. We study the business context with semi-structured interviews of experts of the company i.e., BIM manager, general foreman, site foreman, process engineer, and project manager. Developing a decision support system is seen as an opportunity to reshape workflow and project organisation and improve productivity.

In step (2) business processes are modelled thanks to the information gathered in step (1) and with feed-back loops from the interviewees. We first model the current system to better understand it and identify its shortcomings. Figure 1 shows the as-is system modelled according to IDEFØ and UML rules. It depicts the as-is process workflow from a macroscopic point-of-view. It is composed of three sub-functions: (a) The contractor receives the as-designed DMU of the project, along with other information about the project. The BIM DMU is enriched to create the process view that process engineers will use to carry their work; (b) process engineers and industrial designers use this DMU to design a construction method based on their own experience and other information; (c) Schedules, drawings, resources list are extracted from the DMU and sent to the construction site team. As an extra-step we consider the gradual creation of the as-built records. We also represent the as-is system as a use case UML diagram in figure 2. The figure shows that the general foreman is at the centre of the system to coordinate work in the design office and on the construction site. The general foreman manages site operations and is supported by engineering teams in the office who develop construction processes, plan operations, and purchase resources while maintaining true to the budget and delays. The client is also included in the system as they assess the work done to ensure completion of the project. On site the work is carried by workers and sub-contractors who receive orders from the general foreman and the site foreman. According to Spie batignolles experts, socio-technical changes are putting an increasing stress on general foremen because they play a key role in planning and managing site operations. They are the link between the design office and the construction site and are expected to deal with unresolved design issue while managing ongoing operations and testing new technological applications. This situation could be partly explained by the work organisation as shown in figure 1. Process design is a one-way activity, from the design office to the construction team. The construction team is expected to build according to the documents given by the office. Design issues often come out during construction operations and construction teams are expected to resolve them.
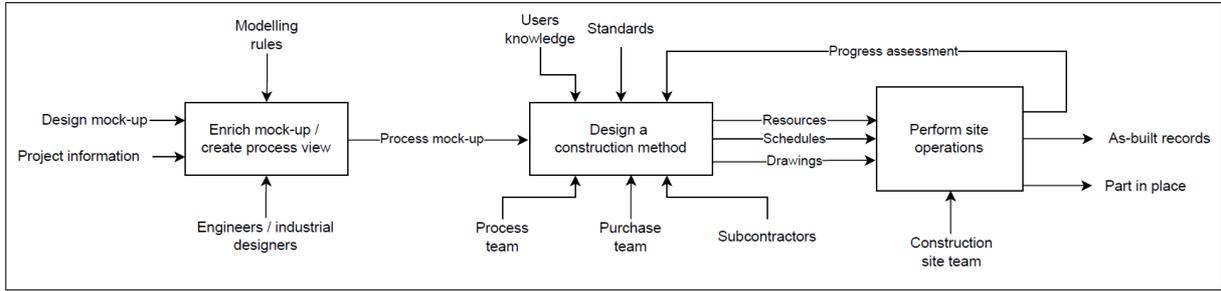
FIGURE 1 – Process modelling of the as-is system (IDEFØ diagram) (Blampain et al., 2022)
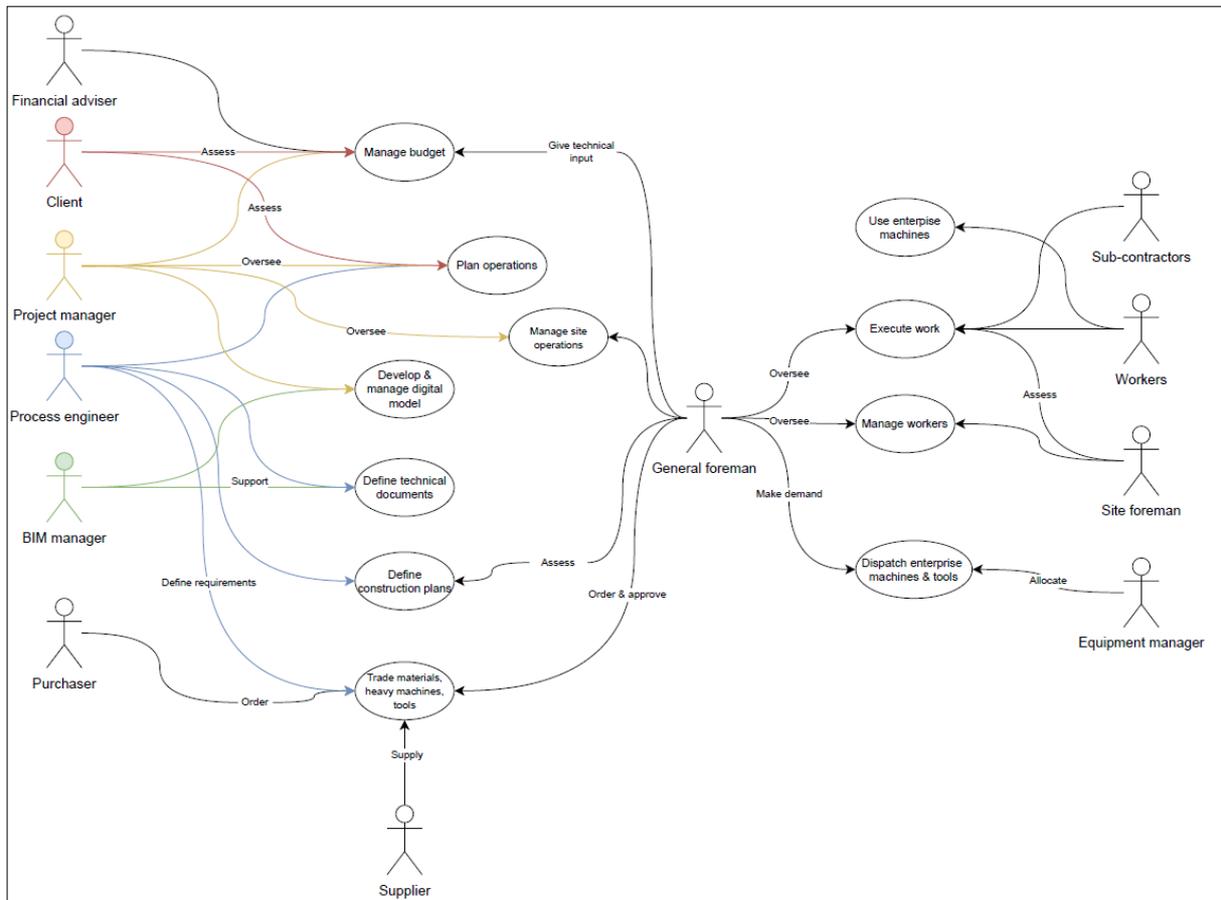


FIGURE 2 – Site management as a use case of as-is system (UML diagram. Colours are here to help readability) (Blampain et al., 2022).

Based on figure 1 and figure 2 we specify the new process system, shown in figure 3. It represents a hypothetical workflow that rely on the to-be-developed system. The system can be decomposed in four sub-functions: (a) The contractor receives the as-designed DMU of the project, along with other information about the project. The DMU is enriched to create the process view that process engineers will use to carry their work. The resulting DMU is called "Process DMU"; (b) process engineers and industrial designers use the Process DMU to suggest a construction method based on the enterprise knowledge and other documents; (c) the result is a 4D DMU, sent to purchase and production teams that will assess it, the client may also assess it if needed; (d) if the suggestion is a no-go we go back to step (3), if the suggestion is a go,

production teams use the information contained in the DMU to carry their work. As an extra step, we consider the gradual creation of the as-built DMU.
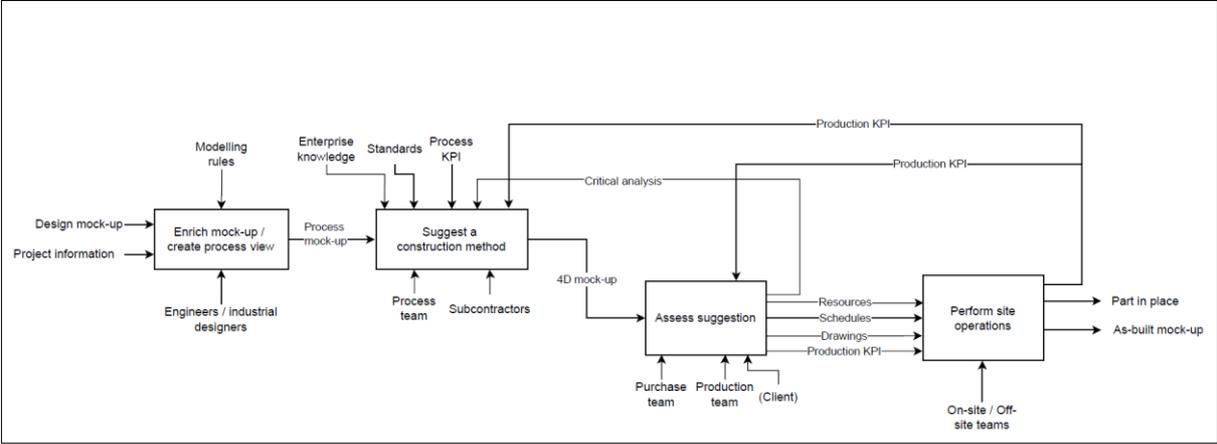


FIGURE 3 – Process modelling of the proposed system (IDEFØ diagram) (Blampain et al., 2022)

In step (3) we present figure 3 to the experts interviewed in step (1) to refine the model. We carry a detailed functional analysis with the help of the same experts to further describe the information system from a process and function point-of-view. This step can be supported with insights from scientific literature. Figure 4 depicts a first draft of the software functions of the system and their interactions. The digital mock-up management and planning function play key roles in this system because they produce the main outputs. Communication and synchronous work functions ensure a seamless workflow between all stakeholders. Together with resources and financial management functions, all these features represent the exhibition of the contractor BIM strategy. These functions are controlled by external information such as the enterprise knowledge-management data base and interfaces with other EIS such as the ERP. All the functions converge into the site operation progress management function that represent the work done on-site. A new work organisation is needed to use this system. A new stakeholder relationship system will be devised and tested with the system. This new organisation will be developed based on the models of figure 2 and figure 3. It will be designed so as to dived work activities more equally between the design office teams and construction site team. The main goal is to change the general foreman work to reshape it into a production-oriented work.

In step (4), we use the detailed functional analysis to develop a prototype of the system. We then test it on uses cases. During the software development, construction projects will be selected with Spie batignolles in order to brief the project teams beforehand and make the preparation work.
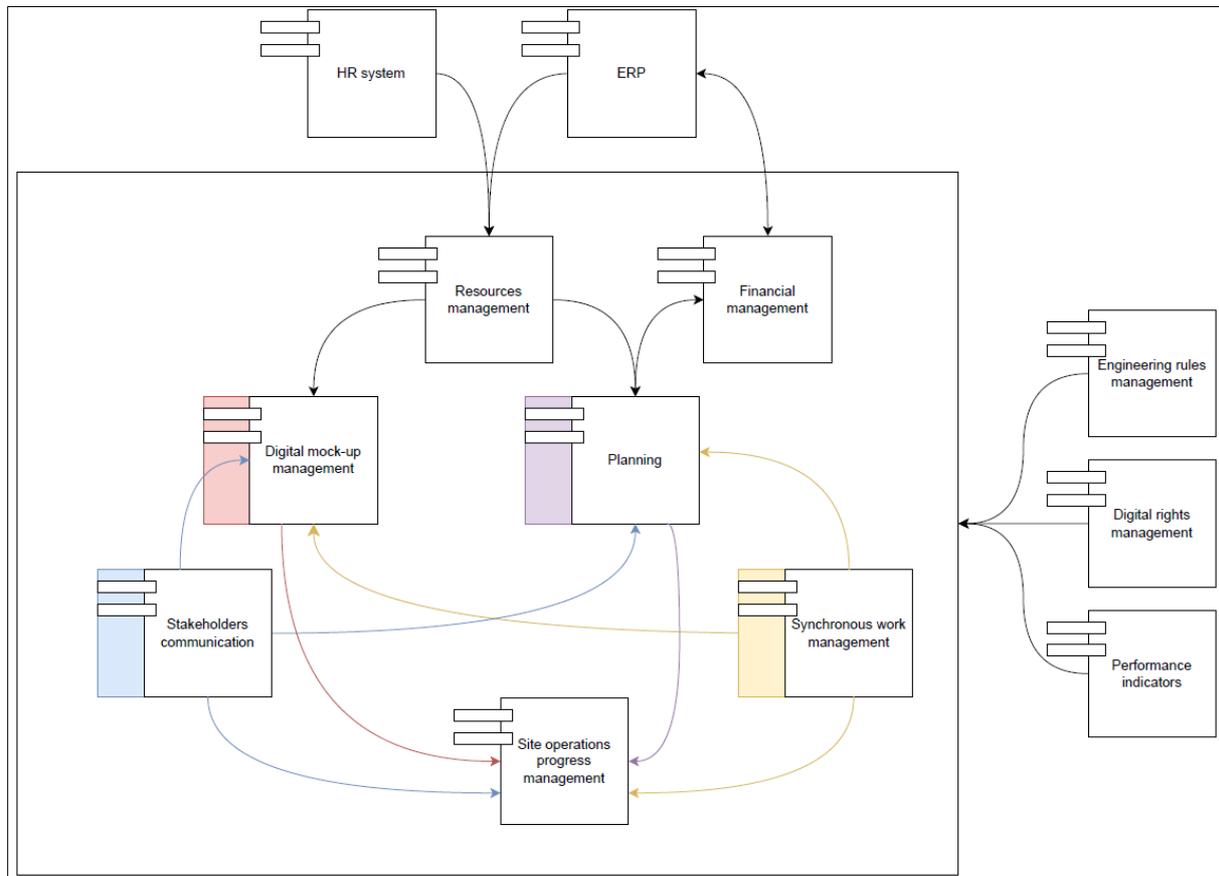
FIGURE 4 – Proposed information system components for site planning (UML diagram. Colours are here to help readability) (Blampain et al., 2022).

## 5    Conclusion and future work

The construction industry is changing and faces new challenges, engineering practices must adapt to different context and deal with new constraints. There is a need to transform project management practices to include BIM at a greater level, most notably during the construction phase. BIM gives the opportunity to professionals to rethink how to design, build, and operate a building through data- and knowledge-based processes. 4D BIM allows to rethink how building parts are built and how production workflow and supply chain are organised.

This paper has presented a conceptual description for a decision support system designed to help general contractor in their work to dynamically plan construction and site operations. The digital solution architecture and associated methodology are based on 4D BIM principles and use knowledge-based practices to design building solution through collaborative work between process engineers, purchasers, suppliers, and site managers. The future work will be dedicated to developing the detailed modelling of the system based on our current drafts.

The digital solution only focuses on 4D BIM issues, but we could account for more parameters such as financial characteristics of the project or its environmental impacts. These other BIM dimensions will be investigated to include new input data and develop specific indicators for stakeholders. This digital solution imposes to reshape project management practices through new workflow. Different management methods will be investigated to support the digital and IT development.

We ambition to develop an industrial use case that will be tested with the help of Spie Batignolles on to-be-selected projects.

## 6    Acknowledgement

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