Comparing PLM and BIM from the Product Structure Standpoint

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Conrad Boton[1], Louis Rivest[1], Daniel Forgues[1], Julie Jupp[2]

[1]Ecole de Technologie Supérieure, Montréal, Canada
{firstname.name}@etsmtl.ca
[2]University of Technology Sydney, Australia

Abstract. The increasing use of Building Information Modelling (BIM) across the construction industry highlights the potential for a common endpoint with manufacturing industries. Previous research work has shown that it is possible to improve BIM with the features and the best practices from Product Lifecycle Management (PLM) approach. This article provides a comparison between the PLM and BIM approaches from the standpoint of the Product Structure (PS) and the Bill of Material (BOM). It discusses the need to explicit a structuring concept in the BIM approach in order be able to switch to an information-centric management approach in construction projects instead of the current activity-based approach.

Keywords: BIM, PLM, Product Structure, Bill of Material, BOM, Construction.

1 Introduction

Considered to be refractory to information technology, the construction industry has suffered a great delay in terms of productivity compared to other industries such as aerospace and automotive. The sector is characterized by high fragmentation, heterogeneous project teams and a lack of interoperability. For decades, several studies have explored the role of information technology as an integrating element and enabler of productivity without much success until recently [1–3].

Yet with the rise of BIM [4], the industry seems at a crossroads. Indeed, BIM appears to have the potential to solve a number of persistent problems in the sector (interoperability, optimization of information flows, etc.) that will lead to improvements in productivity [2, 5]. While early studies focused on interoperability issues and other technological improvements, it appeared quite soon that the great value of BIM lay in collaboration and optimization of information flows throughout the project life cycle: unfortunately the source for most of the current limitations of the BIM approach. Recent research [6–8] suggests improving BIM based on best practices from PLM.

Jupp [6] recently studied the consequences of incomplete BIM implementation in construction projects. The results suggest that the PLM approach actually provides interesting features to solve many of the problems currently encountered in the BIM approach. Indeed, similarities exist between the current upheavals in construction and the changes observed in complex manufacturing industries a few years ago with the arrival of the PLM approach [7]. In addition, the philosophy and overall objectives of BIM are similar to the PLM approach.

Recent studies suggest that as a methodology, instead of evolving into a construction-dedicated PLM approach, that BIM and the structured product data stemming from its modelling processes be used to create an effective connection between the application of PLM and ERP systems to construction projects [9]. Holzer presents the Bill-Of-Materials (BOM) as the missing link between BIM and existing (and largely disconnected), feasibility, design, construction and operational processes [9].

The concept of the BOM is widely used in other industrial sectors, and the Product Structure is central to PLM systems. Moreover, “unlike product structures, a BOM cannot store a complete customized products family” [10] and “does not consider the product data that is associated with the technical objects” [10]. However, these two concepts are useful and practical in manufacturing industries to convey information throughout the entire lifecycle of a project.

Since the construction industry is comparable to the other discrete manufacturing industries, despite some notable differences, these concepts then appear to be very interesting directions with good potential in enabling an information-centric management approach in construction projects in the age of BIM.

We could reasonably argue that PLM systems would not be the same without a Product Structure to organize data. However, while the construction industry uses product breakdown structures, comparing PLM and BIM through the way product structure is defined and exploited could bring valuable insight on the differences between these sectors and the tools they use. Ultimately, this comparison could even provide a way to transpose some PLM successes to BIM. This article explores the concepts of BOM and Product Structure in the light of current BIM practices and provides a discussion on how PLM and BIM compare with respect to the notion of the Product Structure as conceived of in discrete manufacturing industries. It first introduces the background through the peculiarities or the construction industry and the related works. It then defines the different concepts and discusses how they can be seen as structuring concepts in the BIM approach.

2 Background

2.1 Particularities of the construction industry

It seems important, before going further, to present a comparison between the construction industry and other manufacturing industries. In a study by Green et al. [11] a comparison between the construction and aerospace industries provides an accurate representation of the differences of context between these industries. They identify two major elements to analyze these differences: the structural differences and the relationship with government. It is generally accepted that the construction sector is larger but still very fragmented and localized, while the aerospace industry has highly consolidated in recent decades due to considerable competitive pressure. In previous research on construction industry fragmentation, Howard et al. [1] distinguish vertical fragmentation from horizontal fragmentation. Vertical fragmentation concerns the fact that a construction project is divided into several more or less short phases. Horizontal fragmentation relates to the fact that multiple different specialist interactions occur during the same phase. The combination of vertical and horizontal fragmentation therefore gives rise to small specialist firms operating on small local markets.

If the last decades have seen the merger of several major players in the aerospace industry to form large blocks, mergers observed in construction remain comparatively low [11]. The structure of the construction industry can be illustrated by a large-based pyramid dominated by small firms. While the dominance in the aerospace industry is made by large companies with a much more widespread technological expertise throughout the supply chain. Competition between firms in construction is done more on cost than on technical expertise. In addition, the combination of technological requirements and the complex network of interdependences in aerospace is a significant barrier for new entrants, which is far from the case in construction [11]. The last structural difference identified by Green et al. [11] is related to the customer base that seems highly diversified in construction but very narrow in aerospace, which is characterized by long-term collaborative relationships between a small number of highly sophisticated clients.

Moreover, unlike aerospace, the construction sector is marked by high flexibility and a strong sense of "laissez-faire" that governments prefer to see as an advantage for the sector [11]. This need for flexibility was confirmed by Kubicki [12] who finds that it occupies a central place especially during the construction phase where mutual adjustment is important. A very recent study showed empirically that there is significant difference between the as-planned activities and the actually-performed activities [13]. In reality, the work processes are usually not documented and they are "voluntarily" informal. This makes traceability of accurate information very difficult.

Despite these differences, the two industries remain altogether comparable for many reasons. Patrick [14] highlights the fact that both try to manufacture a product using appropriate resources (materials, equipment, labor). The product is manufactured using a specific process, and its implementation takes place on a particular site. The quality/cost ratio is very important and there is a need for optimization.

2.2 Related works

Based on an empirical research, Jupp [6] studied the consequences of incomplete implementation of BIM as is currently the case in most applications of the methodology. The study identifies three types of problems: process-based issues, technology-based issues and policy-based issues. The study then identifies the basic features of PLM in order to demonstrate that there are a range of established solutions that cover a large part of these problems. The results show that PLM can actually be an opportunity to expand existing applications of BIM. However the study also suggests that the transverse application of a BIM-PLM solution that is based on discrete manufacturing processes might lead to other types of problems due to the complexity of interfaces observed in construction projects. Indeed, the problems observed in the use of BIM in construction projects are often specific to the client and the project's principal requirements, while the PLM approach is based on generic features. Moreover, the complexity and the large uncertainties of the collaborative environment in the construction industry suggest great caution. In the same period, Aram & Eastman [8] proposed a discussion on the improvement of BIM with PLM functionalities. They noted that it should be necessary to modify and adapt many aspects of current PLM technology before being able to apply it in construction due to the major differences between the construction and the PLM's traditional target industries [8].

Jupp and Nepal [7] explored how BIM and PLM have impacted the professional practices in construction and manufacturing industries. For each industry, they explored the way BIM or PLM change the working practices through the new activities they come with, the new responsibilities and roles, the competencies needed and the relations in the supply chain. The study highlighted the unique characteristics of each industry and PLM and BIM contrasts. They concluded that the level of BIM maturity across the construction industry is improving, increasing the possibility to reach a "common endpoint with manufacturing industries". In the same spirit, Holzer [9] noted that the full potential of the BIM approach has reached a maturity at a level that is possible to consider its integration, through the definition of BOM, with PLM systems, and moreover with the production line. According to this research, the efforts undertaken in the past to link the manufacturing data with construction information in the frame of ERP systems have failed due to the use of 2D CAD that is not best suited for this purpose. With BIM, it is now possible to have the necessary information-centric project delivery approach. So it can be easier to integrate construction processes with product information.

In complement to these researches, many technology-centered works attempted to merge BIM and PLM capabilities into a single technological environment [15–17]. If the effectiveness of these solutions remains to be seen, they have the merit of showing that a sum of features cannot be the solution to issues unresolved in the adoption of PLM, nor of BIM.

3 Product Structure: the missing link in the BIM approach?

3.1 What is it?

Jansen-Vullers et *al.* [18] defined the Bill of Materials as "a list of components required for the production of a parent item". In the form of a network the BOM "goes-into relationships", and usually stores the number and type of relationships between component units necessary for the parent unit [19]. The structure of a BOM differs according to the production environment it is demanded by. Maull et al. [20]

distinguish five different production environments (demanding different BOM structures) including make-to-stock, assemble-to-order, make-to-order, engineer-to-order, and selling capacity. In a make-to-stock environment, a BOM is prepared for each product and a percentage BOM regroups similar final products. In an assemble-to-order environment, modular BOMs are used because it is impractical to define a BOM for each product due to the large variety of products. In make-to-order environments, four different BOM types are used: a planning BOM for forecasting purposes (relationships between product families and components), a standard BOM (semi-finished products released from engineering), a reference BOM (kinds of the product), and an order BOM (used in the case of particular orders from customers). In engineer-to-order environments, because customers change their requirements throughout the life of the product, the BOM is developed gradually. BOMs usually begin in the design-engineering department but are found in the inventory control, procurement, shipping, marketing, manufacturing, field services, and even in the accounting department [21].

There should be no confusion with the Product Structure even if in colloquial language, a BOM is often referred to as a Product Structure [21]. According to Brière-Côté et al. [22], these two concepts are different despite their similarity. As a single-level part list, a BOM, is considered as a simple filtered Product Structure snapshot at some point during the life of the product development [10], and is not identical to a Product Structure [21], which is defined as "an organized hierarchical collection of technical objects that are linked via 'part-of' relationships" [10]. The Product Structure then "describes hierarchically, using items, how a product can be generated from assemblies, sub-assemblies, and components" [21]. Resulting from a logical breakdown technique with particular concerns, the Product Structure stores not only technical objects but also associated product data and customized product families in a dynamic way and according to different views (e.g., a structural view, filtered view, cognitive view) [10]. Figure 1 illustrates a structured view of as-specified, as-designed and as-planned technical objects, product data and customized product families. Eynard et al. [23] noted that all instantiated data are managed and stored in the Product Structure.

In PLM tools, these data are classified using metadata and appropriate links are established between the parts and related files through metadata configurable links [23]. In practice the Product Structure can encompass various data types. Trappey et al. [24] identified at least 10 major data types and functions including product definition, service parts support, material purchase planning, assembly sequence, order entry facility, resource analysis, pricing, cost analysis, manufacturing instruction, and engineering change control. For product design and manufacturing management purposes, PLM systems require, in addition to the product structure manager, a workflow engine which "according to the product structure, sends the right available data at the right time to the right user" [23]. This constitutes an important aspect in optimizing the information flow in the PLM approach.

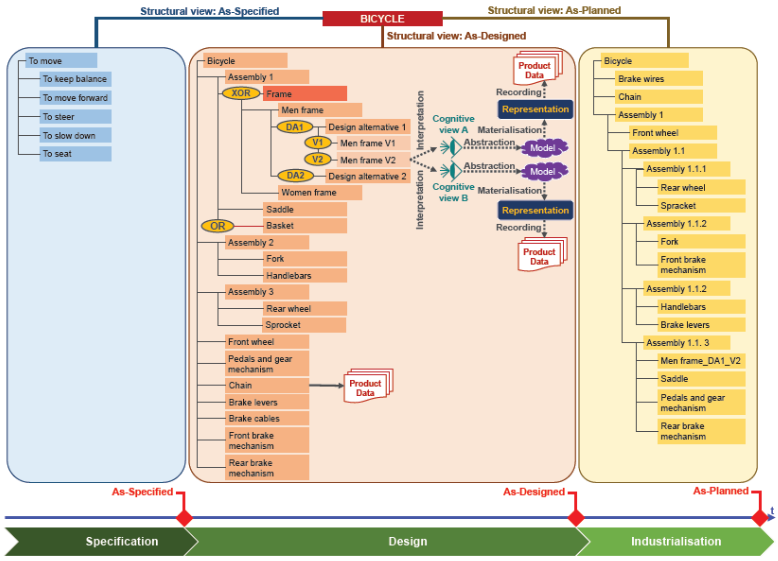

Fig. 1. Example of a multi-view product structure (Source [10])

3.2 The need to explicit a Product Structure concept in the BIM approach

To ensure that the appropriate information is contained within the model, current BIM practices suggest identifying the function of the model and specify the related information requirements prior to implementation so as to develop the model accordingly. Kreider and Messner defined a BIM use as “a method or strategy of applying Building Information Modeling during a facility’s lifecycle to achieve one or more specific objectives” [25]. Twenty-five BIM uses have been identified (e.g., 3D coordination, design review, cost estimation, phase planning, site analysis, mechanical analysis, etc.) with various use frequencies and different impacts in the industry [26]. To define information requirements, a Model Element Table (MET) is used. The MET structure in construction is quite similar to the BOM in manufacture. It summarizes the list of the model elements but also “indicates the LOD [Level of Development] to which each Model Element Author (MEA) is required to develop the content of the Model Element at the conclusion of each phase of the Project” [27] (See Fig. 2). Thus despite their similarity in terms of structure, unlike the BOM which is extracted from the model, the MET serves as base for the construction of the model.

The BIM model is then developed according to the requirements defined in the MET. In current BIM tools, it is possible to generate a model elements hierarchical list and many concepts are used that could be similar to Product Structure, including the Product Breakdown Structure (PBS) and the Model Element Breakdown (MEB).

§ 4.3 Model Element Table *Identify (1) the LOD required for each Model Element at the end of each phase, and (2) the Model Element Author (MEA) responsible for developing the Model Element to the LOD identified.* *Insert abbreviations for each MEA identified in the table below, such as "A – Architect," or "C – Contractor."* *NOTE: LODs must be adapted for the unique characteristics of each Project.*																	Note Number (See 4.4)
Model Elements Utilizing CSI UniFormat™					LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	LOD	MEA	
A SUBSTRUCTURE	A10	Foundations	A1010	Standard Foundations													
			A1020	Special Foundations													
			A1030	Slab on Grade													
	A20	Basement Construction	A2010	Basement Excavation													
			A2020	Basement Walls													
B SHELL	B10	Superstructure	B1010	Floor Construction													
			B1020	Roof Construction													
	B20	Exterior Enclosure	B2010	Exterior Walls													
			B2020	Exterior Windows													
			B2030	Exterior Doors													
	B30	Roofing	B3010	Roof Coverings													
			B3020	Roof Openings													
C INTERIORS	C10	Interior Construction	C1010	Partitions													

Fig. 2. Excerpt of a Model Element Table (MET) [27]

According to Gijezen et al. [28], the PBS "divides the final object in physical systems, components, and elements". The PBS concept is well known in the BIM approach. For example, it plays an important role in 4D simulation where the model creation consists of linking it with the Work Breakdown Structure (WBS) from the schedule [29]. Moreover Gijezen et al. [28] showed how the PBS could be used to improve the clash detection process in 3D coordination. In BIM software, it is also known as the Model Element Breakdown (MEB), as described by Saluja [30], that can be used to create information exchange worksheets. Figure 3 shows an example of a model elements hierarchy list as presented in Autodesk Revit.

Some BIM software dedicated plugins (BOM to Excel[1], SysQue BOM[2], etc.) are emerging, suggesting that the way the MEB is managed in BIM tools seems insufficient to cover practitioners' needs. For instance, if it is possible to extract detailed "materials and quantities takeoffs" from current BIM software such as Revit, it seems not possible to manage the breakdown structure "according to different views" [19] in order to allow the different production environments to make different demands on the structure" [20]. For example, the construction schedule and cost estimate remain as two separate autonomous files in typical approaches to BIM [32].

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[1] http://www.hingepoint.com/products/bom-revit-app
[2] http://sysque.com/sysque-modules/sysque-bom

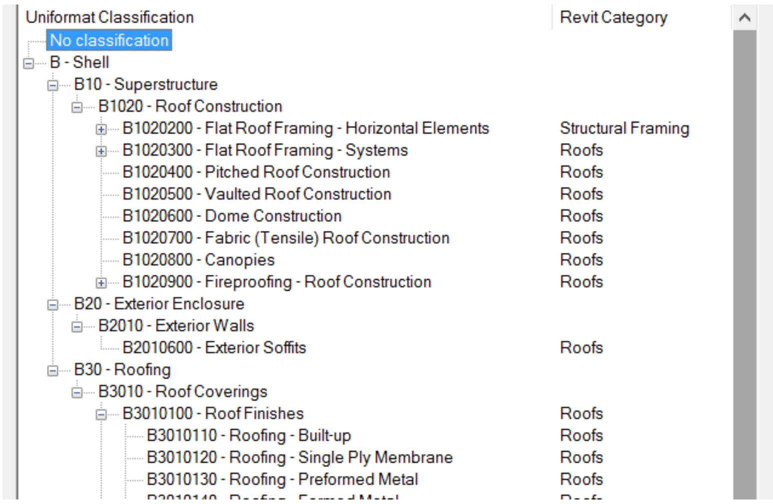

Fig. 3. Example list of model element hierarchies in Revit

The approach taken by Trimble's Vico software does provide the ability for the building information model to become somewhat more integrated relative to the notion of a Product Structure in manufacturing. It achieves this by removing the need to link disparate schedules generated by what are typically separate and independent 3D, 4D and 5D models [32]. The integrated Vico model thus enables the definition of how long it will take to install the amount of materials being derived from the model. This approach reflects a manufacturing mindset as the unified schedule becomes a product of what and how much will be built and represents this in a particular order that has construction logic. Indeed, BIM use encompasses many processes (3D, 4D and 5D) that call for different views of the product structure. Moreover, in the framework of a specific BIM use (e.g. 3D coordination, cost estimation, phase planning, etc.) many sub-processes corresponding to different views are necessary throughout the project lifecycle. For example, based on the study conducted by Monteiro and Martins [31], Figure 4 proposes the different views necessary for the various processes of Cost Estimation throughout the project lifecycle. The purposes of such views are also indicated.

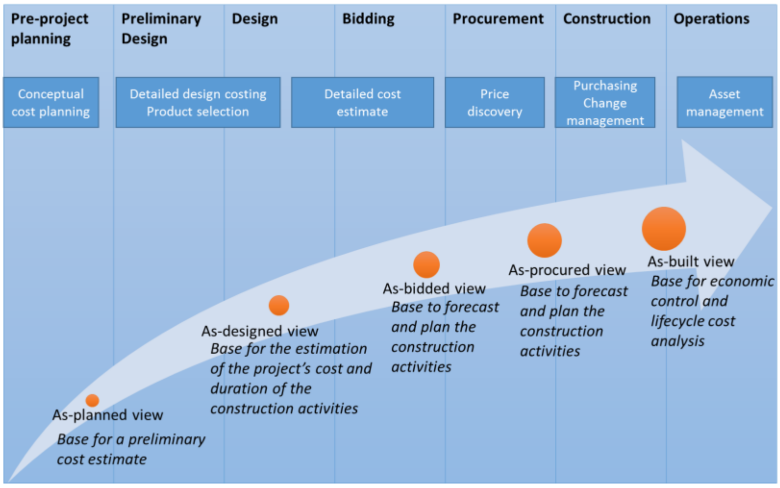

Fig. 4. Possible evolution of the product structure views for cost estimation BIM use

4 Conclusion and future works

Several recent research works have addressed the improvement of BIM based on PLM's best practices. If these works are interesting milestones, a major limitation of current BIM practices lies in the fact that the perspective of construction project management is still activity-based rather than information-centric. To implement an information-centric perspective and fully capitalize the potential of BIM in order to optimize flows within the production line, it is necessary to define a structuring concept linking the BIM model, the BIM uses and the other information flows in the project. This paper proposed a discussion on why and how the Product Structure, well-known in manufacturing industries and less in construction, could be such missing link.

In current BIM approach, it is possible to make correspondences between some of the representations used (Model Element Table, Quantity Take-Off, Design Brief, Contract Program, etc.) and the BOM and the Product Structure in discrete manufacturing. However, and unlike what is seen in PLM, they are all disconnected and aren't linked with associated product data and customized product families. Then, the main gap in expliciting a Product Structure in the BIM tools concerns its integration within the model. That is to provide links and representations of this data for different BIM dimensions (3D, 4D and 5D) and BIM uses purposes. Moreover the model validation (even at the handover stages) is rarely undertaken and the quality of data beyond geometry is largely poor (even naming and layer conventions are often very poor throughout design stages) as the quality of data is not audited systematically and progressively. The discipline-based modelling process (architectural, structural, mechanical, electrical, hydraulic, fire, and site models) requires frequent federation processes that go beyond the typical design coordination reviews and extend into model quality audits.

Future works will deepen the comparison between how PLM and BIM tools allow product structure manipulation. The aim is to provide a factual and precise comparative approach which could eventually, according to the findings, lead to a cross pollination from the PLM approach to the BIM approach. Moreover it will be important to study how the IFC information model can efficiently be replaced at the heart of BIM practices in order to play the critical structuring backbone role.

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