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Abstract: BIM and PLM are two holistic 3D-based approaches that support the construction and manufacturing industries, respectively. Recently, research studies have emphasised the importance of comparing these two approaches, as it can lead to cross-pollination and mutual improvement. This paper aims to evaluate the functionalities offered by the IT tools adopted by a sample of BIM- and PLM-supported industries during a design/engineering change management (D/ECM) process to identify potential opportunities for improvement. Four case studies with partners from both industries are presented. Firstly, the D/ECM processes of the industrial partners are described. Secondly, the tools used to control documents are identified and explored. Finally, the functionalities offered by these tools are compared, highlighting their main similarities and differences. Through this study, it was found that the PLM tools presented in the case studies offer some advanced functionalities, particularly related to revision management, impact analysis, and workflow management.

Keywords: design change management; DCM; engineering change management; ECM; building information modelling; BIM; product lifecycle management; PLM; document management; tools; process; comparison.

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1 Introduction

Building information modelling (BIM) has been introduced to the construction industry as a business approach based on 3D models that can lead to improvements in productivity (Mesároš et al., 2022). Indeed, BIM is described as one of the most promising approaches to achieve digitalisation in the construction industry over the whole building lifecycle (Krämer and Besenyői, 2018). The trend towards digitalisation in the construction industry came a bit late compared to other industries like automotive and aeronautic,

where product lifecycle management (PLM) has been established since the '90s (Stark, 2016). BIM and PLM have several similarities regarding data sharing, project management, team organisation around deliverables and timeframes, and object-based visualisation activities (Jupp and Nepal, 2014). However, BIM and PLM also differ in terms of the tools, workflows, and standards defined to achieve each approach (Boton et al., 2016). BIM provides great functionality for managing different building processes from design through construction, but it lacks a monitoring and management mechanism (Cheutet et al., 2018). On the other hand, PLM provides powerful management capabilities for the whole lifecycle of any constructed project (Cheutet et al., 2018). A comparison of BIM and PLM can be helpful in improving the two worlds through cross-pollination (Pourzarei et al., 2020). Research by Di Biccari et al. (2018) indicates that the construction industry could benefit from the manufacturing sector's extensive use of PLM in sharing information at different phases of the lifecycle to compensate for its main missing features. The comparison of BIM and PLM can bring various benefits, such as increasing productivity, making production more cost-effective and sustainable, optimising design, minimising production waste, managing the supply chain, standardising product components, and managing product changes and adoptions (Di Biccari et al., 2018).

Several research studies have thus focused on comparing BIM and PLM from different standpoints. Boton et al. (2018) provided a comparison between BIM and PLM from the standpoint of product structure (PS) and the bill of material (BOM). Di Biccari et al. (2018) examined whether the concept of a 'configuration' view, or more accurately, 'product structure configuration' of complex manufacturing, has been applied to process or information management for different phases of the AEC industry's lifecycle. Tiaya et al. (2021) studied how BIM and PLM mock-ups are used for occupational health and safety risk prevention and propose a combined approach for more effective risk mitigation, particularly in industrial facilities. Blampain et al. (2023) explored the industrialisation of the construction industry by leveraging digital solutions, particularly by adapting BIM practices inspired by PLM. Mansoori et al. (2022) explored the use of productisation and product structure to enhance BIM implementation and information consistency in the construction industry.

Among the processes that exist in both BIM- and PLM-supported industries, the process that manages changes made to release documents is an important one. These changes are known as 'design changes' in the construction industry and as 'engineering changes' in the manufacturing industry. According to Jarratt et al. (2011), an engineering change can be handled and understood from various perspectives. The main ones are process, tool, and product perspectives. Different research studies proposed various processes and tools to manage design changes in the construction industry (Hwang and Low, 2012; https://www.construction-institute.org/resources/knowledgebase/best-practices; Mejlænder-Larsen, 2017; Sacks et al., 2018) and engineering changes in the manufacturing industries (Jarratt et al., 2011; Mutingi et al., 2015; Shakirov et al., 2021; Altner et al., 2022).

During the design/engineering change management (D/ECM) processes, a new revision of a document is released after a proposed change is approved. The document revisions must be managed to ensure that the right person gets the correct revision at the right time. The tools adopted by BIM- and PLM-supported industries to manage documents offer various functionalities that can be exploited during a D/ECM process.

This paper aims to characterise the similarities and differences between IT tools functionalities used by a sample of BIM- and PLM-supported industries for design/engineering change management. It is a part of a research study where the authors compare the BIM and the PLM industries from the standpoint of D/ECM. Given the complexity and non-trivial nature of comparing industries supported by BIM and PLM, this study aims to provide a first overview of the D/ECM processes utilised in four distinct samples from both industries.

Data has been collected from four industrial partners, which include two BIM-supported companies, one PLM-supported company from the aeronautic industry, and one BIM/PLM-supported industry. A series of semi-structured interviews have been held with the industrial partners to map their D/ECM process and to identify their document management tools. Next, the functionalities of these tools have been investigated and compared.

The article is organised into six main parts. Section 2 proposes a review of the recent related works. Section 3 presents the research methodology adopted during this study. Section 4 shows the cases studies, focusing on the presentation and comparison of tools' functionalities. The results are discussed in Section 5. The work is concluded in Section 6.

2 Background concepts and literature

This section presents the D/ECM context in the construction industry supported by BIM tools and discrete manufacturing industry supported by PLM tools. This article describes these industries by the terms BIM-supported and PLM-supported industries, respectively.

2.1 Design change management in the BIM-supported industry

Design changes are inevitable throughout the lifecycle of the construction project (Padala et al., 2022). A design change is defined as any change to the design or the construction of a project after the contract is awarded and signed (Hao et al., 2008). Design changes are usually issued to cover variations in the scope of work, material quantities, design errors, and unit rate changes (Khalifa and Mahamid, 2019). Design changes can significantly impact a project's cost and schedule overruns (Moayeri et al., 2017). Moreover, change orders are considered as the largest source of construction waste (Porwal et al., 2023).

Design changes must be managed through a well-structured change management process to avoid contract disputes between the stakeholders (Hao et al., 2008). It is essential to emphasise that there is no unique change management process for the design change in the construction industry. Indeed, many design change management processes have been proposed in literature to help keep design changes under control. A few examples of them can be summarised as:

- Hwang and Low (2012):
  1 identify changes
  2 evaluate changes
  3 implement changes

4 learn from past experiences.

- Mejlænder-Larsen (2017):
  1 identification
  2 filtration
  3 evaluation
  4 approval
  5 implementation.
- Sacks et al. (2018):
  1 request for information
  2 change order
  3 change notification.

Adopting BIM in the construction industry helps reduce design changes but not eliminate them (Eastman et al., 2011). The use of BIM allows all members of the design team to collaborate more efficiently and accurately, which is particularly important in the case of design changes (Li et al., 2021).

Several research studies have proposed some tools to deal with design changes. Nour et al. (2006) recommended using object line number identifiers and industry foundation classes globally unique identifier (IFC GUIDs) to create a database for labelling revisions of the design model. Yet, the existing IFC standard does not allow for the exchange of modifications between various BIM models or for tracking previous changes' history (JalyZada et al., 2014).

Moayeri et al. (2017) created an add-in model checker that uses a component-to-component (ID-to-ID) comparison to identify altered elements in BIM models.

Juszczyk et al. (2016) have developed automated BIM tools that support design change management and allow load and compare two or more IFC format revisions; visualise changes by highlighting altered components and their attributes, and analyse change impacts on costs.

Likhitruangsilp et al. (2018) have proposed a system consisting of several integrated tools (Revit, Dynamo, Excel, VBA). It allows the comparison between BIM models and highlights changes via colour-coded 3D visualisation. The comparison results can be used in estimating cost and schedule impacts.

The listed studies show how BIM tools can visualise and track design change management. The focus of the previous studies was on using either developed tools or a combination of BIM tools to determine the impacts of the design changes on the schedules and cost of the construction projects. Yet, fewer studies focus on describing the functionalities offered by BIM tools to manage documents during a design change management process.

2.2 Engineering change management in PLM-supported industry

The PLM-supported industry is characterised by the variety and constant evolution of its products. Different departments are involved in designing and producing products that fulfil the clients' requirements. Engineering changes have been defined by Jarratt et al.

(2005) as "an alteration made to parts, drawing or software that has already been released during the product design process. The change can be of any size or type; the change can involve any number of people and take any length of time". Engineering changes occur throughout the entire life cycle of a product, from the time a concept is selected to when the product goes out of service (Jarratt et al., 2011).

To control any changes that may be raised, companies adopt engineering change management (ECM) processes and systems. The ECM process is considered as an excellent example of a business process in the PLM environment. It helps in modifying products in a controlled manner (Stark, 2020).

There is no international standard ECM process that companies can follow. Each company has to create and implement its process (Stark, 2020). However, some standards can be adopted as guidance in documents, such as the International Organization for Standardization (ISO 9001:2015) and the International Organization for Standardization (ISO 10007:2017)

According to Stark (2016), it is necessary to model the ECM process. It is essential to define the numerous steps, reviewers, approvers, and sign-off procedures. If an activity does not occur, the definition should specify hierarchies so that it is automatically handed to the subsequent highest authority.

From the literature, we find that several engineering change processes are proposed. Different authors divide the engineering change process into various phases, for example:

- Jarratt et al. (2011):
  1 engineering change request
  2 identification of possible solution(s)
  3 risk/impact assessment
  4 selection and approval
  5 implementation
  6 review.
- Mutingi et al. (2015):
  1 propose
  2 approve
  3 plan
  4 implement
  5 document.
- Shakirov et al. (2021):
  1 change request creation
  2 identify potential solutions
  3 risk/impact assessment
  4 decision on a change by the EC board
  5 implement the change in engineering
  6 implement the change in manufacturing.

- Altner et al. (2022):
  1 change trigger
  2 engineering change request raised
  3 identification of possible solution(s)
  4 assessment of solution(s)
  5 selection and approval of a solution
  6 implementation of solution (engineering)
  7 implementation of solution (manufacturing)
  8 review of change process.

PLM presents a developing approach and an integrated and distributed software tool to foster the process of change management. It accomplishes this by streamlining the processes of idea/comment collection, tracking entries, central data collection, data arrangement and analysis, recurring processes of approval, and documentation changes. After documentation changes, PLM also helps in up-to-date data accessibility for implementation and references (Saaksvuori and Immonen, 2008).

Several tools and methods have been proposed to manage changes within the context of PLM such as the model-based definition (MBD) approach that enables the integration of drawing annotations directly onto a 3D model, thereby minimising the need to generate engineering drawings (Quintana et al., 2012). The introduction of digital twin for the ECM process enables its continuous quantitative assessment and improvement of engineering process planning (Shakirov et al., 2021). And also the implementation of a model-based system engineering (MBSE) to trace and manage changes and also analyse future change impacts more precisely (Pfeiffer et al., 2023).

2.3 Summary

The above literature review provides an overview of the D/ECM processes in BIM- and PLM-supported industries by presenting the proposed process to manage engineering/design change in each industry. Despite the differences in vocabulary used in each industry, the activities of the D/ECM process phases remain similar. To classify the D/ECM activities of our industrial partners, we will adopt a unified D/ECM process that contains four phases, adapted from Maurino (1993):

- Request (design/engineering change request – D/ECR): in this phase, an engineering change request is raised to report on a problem.
- Instruction (design/engineering change proposal – D/ECP): the request is analysed and potential solutions are proposed. One of the proposed solutions will be adopted by a change board composed of various stakeholders.
- Execution (design/engineering change order – D/ECO): in this phase, the selected solution is implemented by updating the impacted documents.
- Application (design/engineering change notice – D/ECN): the applicability of the ECO is evaluated so as to determine at what moment or to which units the new product definition will apply, and appropriate communications are launched.

The aim of this study is to compare the functionalities of IT tools adopted by a sample of BIM and PLM-supported industries for managing documents during the D/ECM processes in the BIM- and PLM-industries. By conducting this study, we hope to shed light on potential areas for improvement in the D/ECM processes of these industries, which could ultimately lead to increased efficiency and effectiveness in project management.

3 Methodology

This paper compares the functionalities offered by document management tools adopted by BIM- and PLM-supported industries to support their D/ECM process. The selected approach was to work from the D/ECM process as implemented in actual projects, representing a sample of current real-world practices. The research methodology thus includes three main phases: collect data, mapping D/ECM processes, and compare tools functionalities (Figure 1).

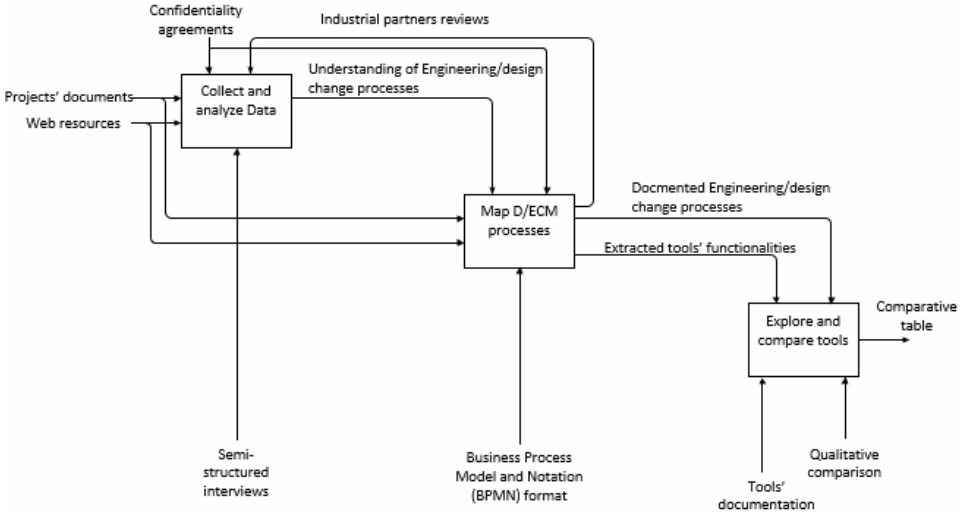
First, data was therefore gathered from four industrial partners. The first industrial partner (A) is a Canadian construction company in Montreal and provides services for managing construction projects. The second industrial partner (B) is a French construction company offering civil engineering, foundation, energy, and development services. The third industrial partner (C) is an energy services company. The fourth industrial partner (D) is a global leader in the aerospace industry. Industrial partners were selected based on different criteria that mainly considered the capability to contact top-level management and the availability of a design change management responsible. These criteria facilitated our access to data.

Data collection has been conducted with 22 semi-structured interviews with interviewees in key positions related to our industrial partners' D/ECM processes. In the semi-structured approach, a set of questions are prepared to guide the interview, but the interviewee has a lot of freedom in responding. In other words, questions may not be answered in the order listed on the schedule. As the interviewer notices items expressed by interviewees, questions not contained in the outline may be asked. During these interviews we asked our partner to describe their D/ECM processes. Since a partner may deal with a different D/ECM process from one project to another, we asked them to describe the different phases of a D/ECM process from a specific but representative project. The average length of the interviews was 1 hour and 30 minutes.

In the second phase, each partner's D/ECM process has been mapped. The Business Process Modeling Notation 2.0 (BPMN 2.0) format has been chosen to model the D/ECM processes. BPMN is a graphical representation of business process steps' logic. This notation was explicitly created to organise the sequence of procedures and messages that pass between the stakeholders in various activities (https://www.bpmn.org/). This format allowed us to depict the activities, the documents, the information flow, and the tools used in each process. In addition, when available, sample documents provided by partners have been analysed to further understand the process. They documented communication like e-mails, contracts, project descriptions, change orders, and requests. During this step, tools used by partners for controlling documents have been identified. The documentation phase was iterative and reached an end with the approval of its BPMN by each industrial partner.

Finally, the functionalities provided by the document management tools were analysed. The authors explored the tools directly by using the tools if available. Otherwise, the authors rely more on the documents offered by the industrial partners to describe the tasks conducted with these tools. This helped depict the role document management tools played during the D/ECM. The exploration leads us to identify the key functionalities used in the D/ECM. Then a detailed comparison between each functionality was conducted to identify similarities and differences by using a descriptive summary table.

Figure 1 Research methodology



4 Case study

4.1 Presentation of the industrial partners

Partner A is a BIM-supported Canadian company located in Montreal, Quebec, Canada, that provides several services for managing construction projects. A private project was selected. It corresponds to the construction of a building phase that will include 250 rental apartments spread over 20 floors in Montreal. During the study, the project was at 90% completion. The project involves different stakeholders collaborating to ensure the project's progress. They are: the client, the project manager, the professionals, the general contractor, and the subcontractor. Our partner plays the role of the project manager in this project. Although design changes cost over 15 million CAD in the studied project, no formally documented DCM process was available.

Partner B is a BIM-supported French construction company specialising in public works, civil engineering and foundations, energy and development, as well as real estate and concessions. The project documented in this study is a private construction project based in France. The design change process that has been documented during this study presents a general design change process where our industrial partner plays the role of the

general contractor. The stakeholders in this process are: the client, the project manager, the general contractor, and the subcontractors.

Partner C presents an energy services company based in Canada that adopt a hybrid solution of BIM and PLM. The D/ECM process documented during this research reflects the process managed within the company departments with the external partner(s). The internal departments are engineering administration, contract administration, 'planning, estimation, and cost control'. The external partner is presented by the contractor and subcontractors if needed.

Partner D presents our industrial partner for the PLM side. It is a Canada-based aerospace manufacturer that adopted a paperless ECM process in 2016. For confidentiality reasons, the authors did not have access to the full ECM process documentation. Hence, a series of interviews have been held with the configuration and design departments to document the ECM process, as for the other partners.

4.2 D/ECM process

In this section, we present the D/ECM processes adopted by our industrial partners. The D/ECM activities of each partner are clustered according to the phases of the D/ECM process proposed in Section 2.3.

Table 1 describes the activities of our four industrial partners during their D/ECM processes. The D/ECR phase, when a request is raised, seems similar to the four cases studied. However, the way of raising a D/ECR may be different. In fact, we found that in BIM-supported partners, the DCRs are usually initiated through email or phone, and the follow-up of the DCRs is generally done through an Excel sheet. On the other side, we find that our PLM-supported partner and our hybrid BIM/PLM-supported partner rely more on their internal configuration management to raise and manage ECRs. In the next section, we discuss the tools used for each partner in depth.

The D/ECP phase focuses on the evaluation of the D/ECR and the proposal of potential solutions to resolve the D/ECR. At the end of this phase, one solution has to be approved. The professionals do the proposal solution for partners A and B. Similarly; partner D creates a group of professionals named integrated product team (IPT) to take charge of the ECP. Interestingly, for partner C, the ECR raiser usually takes charge of proposing a solution that our partner's internal departments evaluate. Another interesting point to mention in this phase is that the proposed solution for the BIM-supported partners includes updated documents, which is not the case for the other partners.

The D/ECO phase executes the selected solution by documenting the approved change proposal. The professionals update the documents that are involved in the approved changes.

The D/ECN phase focuses on studying of the applicability of the D/ECO and the notification of the communication of the updated documents to the stakeholders involved. We can see that this phase seems to be more complicated on our BIM-supported partners' side. In fact, while partner D assigns a budget to the change since the D/ECR phase, the change cost is discussed at the D/ECN phase for the BIM-supported partners. At this stage, negotiations are held with the general contractor and the subcontractors to agree on the cost and how to implement the change.

Table 1 D/ECM process for all four industrial partners

D/ECM phase	*Partner A*	*Partner B*	*Partner C*	*Partner D*
D/ECR (request)	• A DCR is initiated by the client or after raising an RFI by the contractor or the subcontractors. • The project manager communicates the DCR to the professionals. • The project manager follows up the DCRs.	• A DCR is initiated by the client or after raising an RFI by the general contractor. • The DCR is communicated to the professionals.	• An ECR is initiated. • The ECR must be indicated in the internal system with a clear description.	• An ECR is initiated. • A budget is assigned to the raised ECR.
D/ECP (instruction)	• The DCR is evaluated by the professionals. • Professionals propose different change directives (CDs) to resolve the ECR. • One of the CD is approved by the professionals. • The project manager follows up the CDs.	• The DCR is evaluated by the professionals. • The professionals provide a list of instructions to be shared with the client. • The client evaluates and approves the instructions.	• The initiator proposes a solution to resolve the ECR. • The ECR and the solution proposed are evaluated by the contract administration in parallel with the engineering department, design department, and planning department to determine the impact of the change on the schedule and cost of the project. • The evaluation is sent to the contract department to approve the change and the proposal.	• The design manager receives and evaluates the ECR. • The design manager prepares an integrated product team (IPT), formed of professionals, to take charge of the change. • The IPT creates a design intent document (DID) that includes the ECR and the change proposals. • The proposals go through a series of reviews and then get approved by the design manager and the IPT.
D/ECO (execution)	• Documents are updated by the professionals based on the approved CD.	• Documents are updated by the professionals based on the approved instructions.	• The documents are updated to include the approved change.	• The configuration management (CM) department create an ECO based on the DID.
D/ECN (application)	• The updated documents are communicated to the contractor and subcontractors. • The contractor and subcontractors propose their bids to execute the change. • The client approves the bids.	• The updated documents are communicated to the contractor and subcontractors. • The contractor and subcontractor propose their bids to execute the change.	• The updated documents are shared with the stakeholders. • The change is executed by the contractor under the supervision of the contract department.	• The CM department assign the ECO in daily issue list. • The change is implemented.

During the D/ECM process, different documents are exchanged and updated before being implemented. Managing these documents remains a crucial task for the effectiveness of the D/ECM process. In the next section, we focus on identifying and comparing the functionalities of the document management tools adopted by each partner during his D/ECM process.

4.3 IT tools involved in partners' D/ECM process

Various tools are used by our industrial partners to support their D/ECM processes. Table 2 lists these tools and classify them into edition and management tools. Whereas Autodesk products present the dominant edition tools for the construction partners, we find that Catia V5 from Dassault Systems is the tool used by the aeronautic partner. As a hybrid company, partner C uses both Autodesk and Dassault Systems as edition tools. For the management tools, we observe that Excel is present in all four partner companies. Excel remains an important tool for users to manage and track their documents. While companies A and B rely only on commercial tools to manage their data, we find that companies C and D use some in-house configuration management tools.

Table 2 Adopted tools in D/ECM process

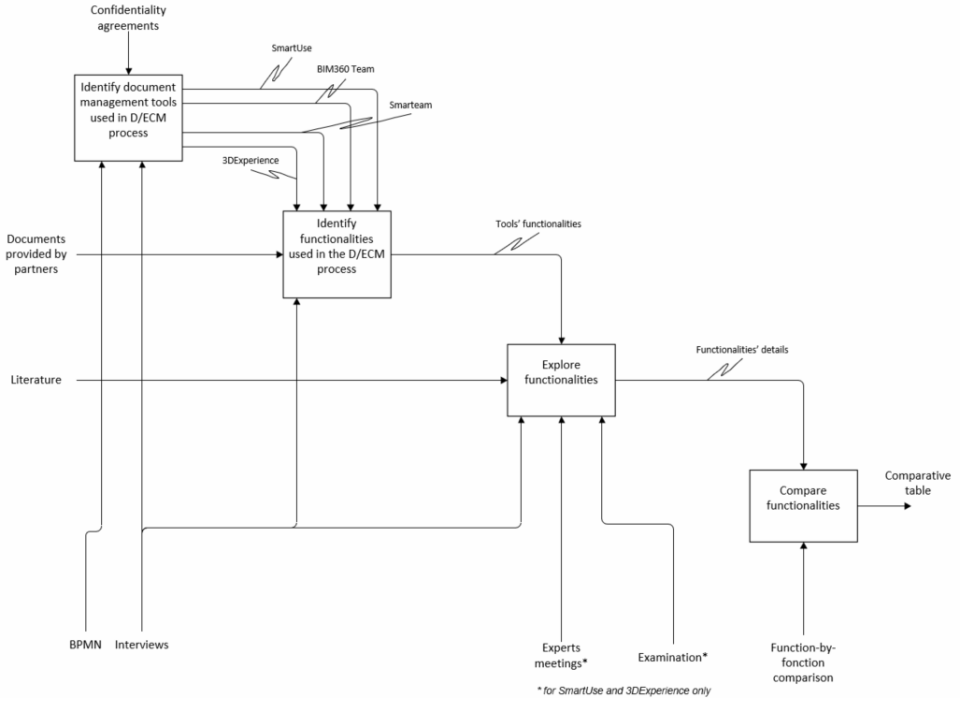
	Tools	*Partner A*	*Partner B*	*Partner C*	*Partner D*
Edition	AutoCAD	✓	✓	✓	
	Revit	✓	✓	✓	
	Civil 3D			✓	
	3D Max			✓	
	Catia V5			✓	✓
Management	Excel	✓	✓	✓	✓
	SmartUse	✓			
	BIM360 Team		✓		
	SmarTeam			✓	
	3DExperience				✓
	In-house configuration management tool			✓	✓

During this research, we focus on presenting and comparing the functionalities of the document management tools adopted by our partners to manage documents during a D/ECM process. These tools are SmartUse for partner A, BIM360 Team for partner B, SmarTeam for partner C, and 3DExperience for partner D. These tools are referred to as document management tools in this article. Studying other management tools functionalities such as Excel, and the in-house configuration tools is considered to be out of the scope of this study. The document management tools that are being compared in this article are presented as follow:

- SmartUse: presents an electronic document management system that helps different stakeholders embedded in a construction project work collaboratively. By managing electronic documents, SmartUse helps implement a paperless culture in the construction industry.

- BIM360 Team: a cloud-based collaboration platform developed by Autodesk that enables architects, engineers, and stakeholders in their projects to work effectively together in a single central workspace. Over 100 2D and 3D file formats can be viewed, marked up, shared, and reviewed by users on any device (browser or mobile).
- SmarTeam: a product data management system offered by Dassault Systems that provides collaborative offerings focused on product development processes, supporting design, engineering, and business activities. A unified platform for all SmarTeam products enables collaboration between users across these domains. Companies can tailor the solution to facilitate collaboration across global organisations or supply chains as needed.
- 3DExperience: a cloud-based collaborative environment developed by Dassault Systems. The platform is a connected online environment where all the design, collaboration, and data management capabilities are stored in a single user interface. 3DExperience is considered to be potential candidate to replace SmarTeam.

Figure 2 Approach for comparing IT tools functionalities for a D/ECM process



4.4 Comparative analysis

4.4.1 Comparison approach

The authors have followed four main steps to compare the functionalities of the IT tools used by the industrial partners during a D/ECM process (Figure 2). First, the authors

identified the document management tools adopted during the D/ECM. The identification was done through the semi-structured interviews and the documented BPMNs. That step ended up by identifying four tools which are presented in the previous section. Second, the functionalities offered by each tool and used during the D/ECM where identified. The authors relied on the interviews with the industrial partners and their documents to understand their practices. Third, the functionalities were explored based on the documentation offered by the tools' organisations on form of guides or webinars (Literature). In order to get more details, the authors have assessed in meeting with some tools' publisher (like SmartUse) or tools expert user (like 3DExperience). SmartUse and 3DExperience were also used by the authors. However, it was not possible for the authors to use BIM360 Team and SmarTeam since they are no more maintained by the organisations (Autodesk and Dassault Systems, respectively). Finally, the comparison between the tools' functionalities is done function by function indicating their similarities and differences.

4.4.2 Comparison results

Table 3 presents a comparative analysis of the tools' functionalities used by the industrial partners during a D/ECM process. The process can be initiated by any stakeholder and at any time. The issue management functionality offered by SmarTeam, 3DExperience, and SmartUse allows users to raise, assign, and track their issues within the document management tool. It is essential to mention that some issues can be raised by email and tracked by an excel sheet in our partner A practices. The BIM 360 Team users (partner B) use the annotation functionality to communicate their issues directly on the documents and rely on Excel to track the issues.

The annotation functionality is available in the four studied tools to annotate and comment 2D documents using predefined shapes (i.e., circles, arrows, clouds, etc.) or freehand mark-ups. BIM 360 Team, SmartUse, and 3DExperience users can also annotate 3D documents. The viewing functionality helps the user visualise documents and the added annotation to evaluate the raised issues. It is also possible to navigate through models, take measures and create sections. BIM 360 Team and 3DExperience users do not require a native CAD tool to visualise the 3D models since they can be opened directly on a browser. SmarTeam users, from their side, need to have the documents saved on their central vault to view them. The central vault presents the repository used to share documents. Documents can also be transferred to other users by email or hyperlink. The users of BIM360 Team and 3DExperience can share documents via communities that regroup different users. Documents can also be shared through accessible files.

The file management functionality is used to store and organise documents. The document can be classified into folders. As we have seen by some partners, documents can be classified by departments (architectural, mechanical, etc.) or by type (RFIs, directives, change orders, etc.) in a D/ECM context. The four studied document management tools show high similarity in managing files where users can create, edit, and arrange files. 3DExperience has the particularity of providing file status visibility. A file can be either private (content visible to members only), public (content visible to all users), or protected (content with maturity 'released' or 'obsolete' visible to all users). For the other tools, a file remains invisible until adding a user.

Adding users to files is controlled through the access management functionalities. Accesses are managed by assigning roles to users. Generally, the project manager takes

charge of assigning roles to other users. Accesses are related to the assigned roles. Access management can be used while creating the change board to ensure only necessary users are added. A project manager can promote or cancel a user role. For BIM 360 Team and 3DExperience, users can also request roles.

The studied tools offer some functionalities to help professionals analyse the impact of a proposed change. We can observe that the comparison feature is present in all of our studied tools. While SmartUse only compares 2D documents, the rest of the tools offer the possibility to compare both 2D and 3D models. The comparison functionality is often helpful in comparing two revisions of the same drawing or model to observe the change that has been applied. SmarTeam and 3DExperience offer another necessary functionality to track change propagation. Users of these two tools can display all the related documents to a selected document and the impacted revisions of that document to determine the potentially impacted documents in case of a change.

Once a change is implemented, a new revision of the change document must be released. The revision management functionality consists mainly of tracking document revisions and ensuring that the right person gets the right revision document at the right time. All the studied tools allow users to identify the document by revision number. However, SmartUse and BIM360 Team have the particularity of allowing users to detect revision numbers from paper automatically using the optical character recognition (ORC) technology. In an industry where papers still occupy an important role in sharing data, such as the construction industry, OCR technology remains an important feature to facilitate the digitisation of documents. The four studied tools allow users to increment a revision number in a sequence. In other words, when applying a change, a user can only promote a document revision from A.n to B.1, making it the last updated revision. The user can navigate the revision history to review and restore previous revisions. However, a simple incrementation of the revision index may not be sufficient to inform the user of the nature of the change. In reverse, SmarTeam and 3DExperience make the difference between minor revision when the interchangeability is kept and major revision when the interchangeability is broken. SmarTeam and 3DExperience also offer an interesting feature for concurrent engineering by allowing users to create different branches from a revision to studying alternative solutions. In this case, two users can apply various changes separately with no risk of interference. At the end, one alternative will be approved and continue to be released. SmarTeam allows users to check out a revision from the shared vault to their local machine to apply changes to prevent simultaneous modification in one revision. 3DExperience offers a similar feature by allowing a user to reserve a document making it non-editable to other users.

The phases of a D/ECM can be defined and managed through the workflow management functionality offered by 3DExperience and SmarTeam. The former helps automatically control engineering change processes by allowing users to create change requests, change orders, and change actions. In the change request, the user can identify problems. Next, in the change order, the way of implementing the change is defined. Finally, roles are assigned in the change action, and the impacted documents are shared. Similarly, change requests and change orders can be created through SmarTeam. In contrast, these features are not presented in the tools adopted by the BIM-supported industries, where workflows were raised and tracked by emails and Excel sheets.

Table 3 Comparison of available D/ECM tools' functionalities

Functionalities	*Description*	*SmartUse*	*BIM360 Team*	*SmarTeam*	*3DExperience*
Issue management	Raising issues	✓		✓	✓
	Assigning issues	✓		✓	✓
	Tracking issues	✓		✓	✓
Viewing	Viewing 2D documents	✓	✓	✓	✓
	Viewing 3D documents		✓	✓	✓
	Taking measures	✓	✓	✓	✓
	Navigating through models		✓	✓	✓
	Creating section		✓	✓	✓
	Web	✓	✓		✓
Annotation	Annotating 2D documents	✓	✓	✓	✓
	Annotating 3D documents		✓	✓	✓
Sharing	Sharing document on central repository	✓	✓	✓	✓
	Sharing documents via email	✓	✓		✓
	Sharing document via hyperlink	✓	✓		✓
	Sharing document on communities		✓		✓
File management	Creating, modifying, and deleting files	✓	✓	✓	✓
	Arranging files and folders hierarchically	✓	✓	✓	✓
	Add or edit metadata of files	✓	✓	✓	✓
	Files' visibility			✓	✓
	Ranging different types of files' extensions	✓	✓	✓	✓
Access management	Assigning roles for users	✓	✓	✓	✓
	Requesting for access		✓		✓
	Modifying users' role	✓	✓	✓	✓

Table 3 Comparison of available D/ECM tools' functionalities (continued)

Functionalities	*Description*	*SmartUse*	*BIM360 Team*	*SmarTeam*	*3DExperience*
Impact analysis	Comparing 2D documents	✓	✓	✓	✓
	Comparing 3D models		✓	✓	✓
	Comparing by overlay	✓	✓	✓	✓
	Comparing by side-by-side	✓			
	Displaying all documents related to the selected object			✓	✓
	Displaying the last revision of the impacted documents			✓	✓
	Displaying all the revisions of the impacted documents			✓	✓
Version management	Identifying documents by a version number	✓	✓	✓	✓
	Detecting version number using optical character recognition (OCR)	✓	✓		
	Incrementing version number in sequence	✓	✓	✓	✓
	Creating a minor revision			✓	✓
	Creating a major revision			✓	✓
	Creating a new branch			✓	✓
	Navigating through versions' history	✓	✓	✓	✓
	Check-in/check-out a version			✓	
	Reserve a version				✓
Workflow management	Creating change requests			✓	✓
	Creating change orders			✓	✓
	Creating change actions				✓

5 Discussion

The findings reported in this paper present some significant contributions to the comparison between BIM- and PLM-supported industries from the standpoint of D/ECM by comparing for the first time the functionalities of IT tools adopted by industrials companies during the D/ECM processes.

After examining the comparison table, we can notice that the four studied tools share certain essential features such as viewing, annotating, sharing, and file management. However, the comparison also showed that PLM tools adopted by our industrial partners provide more advanced features than those adopted on the construction side (SmartUse and BIM 360 Team). SmarTeam and 3DExperience can help automate the D/ECM process by digitalising the process phase like engineering change request and engineering change orders. The absence of these features in the tools used by the construction partners may be linked to the fact that our construction partners rely more on e-mail and phone calls to raise change requests and follow up on their progresses. Furthermore, the revision management feature seems to be more complete by distinguishing between minor and major revisions and allowing users to create branches from previous revisions. Besides, the check-in/check-out functionality in SmarTeam and in 3DExperience help prevent overwriting revisions after modifications.

Yet, among the practices that could be transferred between our BIM partners and PLM partners is the adoption of one repository to share the data. In other word, the adoption of one single source of truth. This could effectively facilitate the management of data and ensure that the right information is always available in few clicks.

It should be noted that features like workflow management, revision management, and impact analysis can be found in some commercial BIM tools such as Procore and Aconex where the DCM phases are well defined and tasks can be easily tracked. However, collaborative tools that can accommodate all stakeholders involved in a construction project remain a challenge to adopt, as they can be costly and require extensive training, making them unaffordable for smaller construction companies.

The adoption of complex platforms such as 3DExperience could be costly and resource consuming especially for small and medium enterprises. 3DExperience, in one hand, offer a multitude of features and applications that could be overwhelming and less intuitive for users. Besides, depending on the subscription or support agreement, access to regular updates, patches, and technical support might have limitations or entail additional costs. That may explain why our PLM partner is still using a version of 3DExperience from 2014, to avoid updates and associated efforts and issues. On the other hand, SmarTeam is no longer supported by Dassault Systèmes, a situation which will eventually force companies to face the challenges of migrating to another system. In addition, both 3Experience and SmarTeam present challenges in terms of integration with other systems and customisation. To overcome these limitations, C and D partners use independently-developed configuration management tools, in conjunction with commercial tools, which can lead to duplication of data and pose new challenges for ensuring good interoperability between the different tools.

This study also has some limitations that are difficult to avoid. First, the research has considered only on four projects due to the effort required to document each case study. Besides, since this paper focuses on the document management tools adopted by only four partners, the results cannot be generalised and does not pretend to offer a complete overview of the state of document management tools in BIM- and PLM-supported

industries. Further work is required to be able to present such an overview. Second, although SmartUse is not a BIM tool (https://technical.buildingsmart.org/resources/software-implementations/), we find it essential to include it in the comparison since it corresponds to actual industry practice and it presents a good way to share data, especially with contractors who have not fully adopted BIM tools yet. Finally, exploring all the functionalities offered by the adopted tools, especially for SmarTeam and BIM 360 Team, was also quite challenging since they are no longer supported by their companies: Dassault Systems and Autodesk. To overcome this limitation, we relied more on the documentation offered by our industrial partners to depict their practices in using these tools. Thus, we were able to get an accurate view of the use of document management tools in our industrial partners.

6 Conclusions

This paper aims to characterise the similarities and differences between IT tools functionalities used by a sample of BIM- and PLM-supported industries for D/ECM. The research was conducted through semi-structured interviews with four industrial partners from the construction, energy, and aeronautic industries. Each partner's D/ECM process was mapped using the BPMN 2.0 format, validated by the partner, and used to extract the activities and the tools exploited by the partners. Next, the authors identified and explored the tools that are used to manage documents throughout each partner's D/ECM process. Finally, the tools' functionalities were presented and compared to show the main similarities and differences between the tools. The comparison showed that revision management, impact analysis and workflow management are the functionalities missing from our BIM-supported partners' tools in comparison to those available from our PLM-supported partners' tools.

This study provides a first overview of the D/ECM processes utilised in four distinct samples from BIM- and PLM-supported industries. Comparing tools' functionalities offers some hints about how companies can improve their D/ECM practices by incorporating features offered by tools they do not already use. Further work is however required to investigate a larger number of companies, covering a wider variety of D/ECM tools and processes.

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