INTEGRATION OF PLM SOLUTIONS AND BIM SYSTEMS FOR THE AEC INDUSTRY

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ABSTRACT

Product Lifecycle Management (PLM) solutions have been serving as the basis for collaborative product definition, manufacturing, and service management in many industries. They capture and provide access to product and process information and preserve integrity of information throughout the lifecycle of a product. Efficient growth in the role of Building Information Modeling (BIM) can benefit vastly from unifying solutions to acquire, manage and make use of information and processes from various project and enterprise level systems, selectively adapting functionality from PLM systems. However, there are important differences between PLM's target industries and the Architecture, Engineering, and Construction (AEC) industry characteristics that require modification and tailoring of some aspects of current PLM technology. In this study we examine the fundamental PLM functionalities that create synergy with the BIM-enabled AEC industry. We propose a conceptual model for the information flow and integration between BIM and PLM systems. Finally, we explore the differences between the AEC industry and traditional scope of service for PLM solutions.

KEYWORDS

PLM, BIM, PDM, AEC industry

INTRODUCTION

BIM enables creation, integration and reuse of information throughout an AEC project. In the last decade, BIM's adoption in the industry has rapidly grown, making a fundamental impact on improving design and engineering processes, construction workflows and ultimately project productivity. From its advent, widespread efforts have been undertaken to enhance various aspects of BIM platforms from internal modeling capabilities to software interoperability, and to expand BIM's role to the entire lifecycle of the AEC projects. BIM servers (Beetz et al., 2011) are now being developed to provide a large integrated data- and knowledge-base that can be leveraged not only in design and engineering but also in planning and management of component fabrication, construction operations, and facilities maintenance. Hence, BIM's scope, functionality and value are quickly being expanded from merely modeling and visualization to a platform for collaborative processes and resourceful decision-making, aiming to support the whole life cycle of the AEC facilities.

PLM solutions have been serving as the basis for collaborative product definition, manufacturing, and service management by capturing and providing access to product and process information and preserving integrity of information throughout the lifecycle of a product. PLM services have traditionally been provided for manufacturing and aerospace industry but the demand for them has gradually expanded to a broad range of industries, including recently to the AEC industry. In this study we examine the fundamental PLM functionalities that benefit and create synergy with BIM-enabled technologies. We explore the recent trends in PLM solutions like implementation of cloud technology and using Service-

Oriented Architecture (SOA) principles. We discuss development of cost-effective solutions for small and medium-sized companies and their potential impact in addressing some of the limiting characteristics of the AEC industry. We also propose a conceptual model for PLM solutions and BIM servers to harmonize their functionalities. Finally, we briefly point out the differences between the AEC industry and traditional scope of service for PLM solutions that challenge their current implementation in the AEC industry.

PLM SYSTEMS OVERVIEW

PLM solutions can be categorized based on the breath and integration of services they provide. According to (McKinney & Amann, 2012), comprehensive PLM solutions provide (a) collaborative Product Definition management (cPDm) capabilities to gather, visualize, manage, and reuse product related information through services like requirements management, product change management and data synchronization, authorization management, and document management, (b) tools to create intellectual assets (e.g., product modeling, simulation, analysis and documentation tools) and (c) tools for manufacturing process management and automation (e.g., factory floor layout and production planning, and manufacturing workflow automation through Computer Numerical Control [CNC] systems). Mainstream PLM solutions usually support a subset of the above mentioned comprehensive PLM capabilities. Companies adopting PLM solutions usually implement only a subset of the offered functionality.

The PLM concept emerged from Product Data Management (PDM) which started in the 1980s to primarily manage design files created by CAD tools. Over the years PLM tools consistently evolved in various dimensions (Saaksvuori & Immonen, 2008; CIMdata, Inc., 2008): In terms of scope, offered services have expanded to cover not only product definition and design phases but also manufacturing and operations. This expansion has led to PLM systems to act as a hub connecting intangible asset information (i.e. virtual products of design and analysis activities) to physical assets information managed by such systems like Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) (Swink, 2006). Moreover, capabilities of PLM systems have been enhanced to capture, manage, and preserve the created information for the entire product portfolio of a company rather than a single project or product.

Expansions in these two dimensions have moved PLM systems toward acting as Enterprise Information Management (EIM) tools. Moreover, the role of many PLM systems have been augmented from mere managing and retrieving data to improving project and product performance by embedding Business Intelligence (BI) capabilities and supporting decision-making activities. This has been enabled by aggregation of product, process and enterprise data, as well as simulation, analysis, and mining of the collected data.

The major enhancement areas of PLM solutions, in relation to the PDM domain, include (a) support of 3D parametric models in addition to CAD drawings, both for referencing other data, and in some cases, for editing and authoring them, and (b) better facilitating collaborative design and analysis of products. These developments reinforce the recent AEC industry trends of quick adoption of BIM technologies to replace CAD drawings as well as development of processes like Integrated Project Delivery (IPD) and technologies like model collaboration platforms for collaborative design and construction.

Top PLM vendors have integrated various tools to support sharing, visualization, navigation and markup of models. Some systems also support some level of 3D model authoring capabilities. To facilitate collaborative design and analysis, they have embraced an integrated and centralized approach to support requirements management, design review, conflict resolution and change management. In an attempt to provide an all-encompassing description of PLM, (Garetti & Terzi, 2004) defined it as an “integrated business model that, using ICT technologies, implements an integrated cooperative and collaborative management of product related data, along the entire product lifecycle”. We explain the details and provide examples of the developed solutions in the next section.

PLM SYSTEMS: STUDY OF CPDM CAPABILITIES

We reviewed PLM offerings of four of the worldwide top five comprehensive PLM technology suppliers (CIMdata, 2009) including Enovia (Dassault Group), Teamcenter (Siemens), Windchill (Parametric Technology Corporation [PTC]), Agile PLM (Oracle) and Share-A-space (Eurostep). The focus of our review was on capabilities that support design and engineering phases of the supply chain. Figure 1 summarizes the reviewed criteria and capabilities. A detailed description of this review is beyond the scope of this paper. Here, we provide a summary of major findings on technology and business trends:

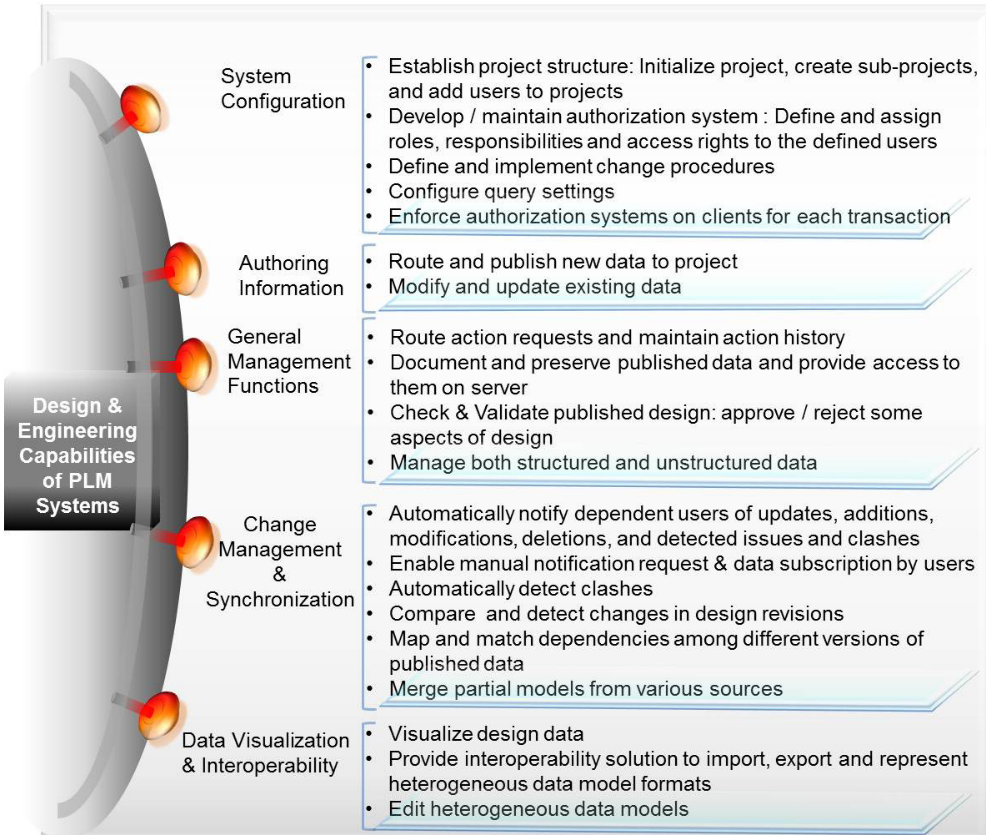

Figure 1: The reviewed criteria and capabilities for collaborative product development management supported by PLM systems

System Configuration

The reviewed PLM systems typically use a multi-level centralized administration system to define and preserve configuration data like user accounts and preferences, access rights, report formats, and revision rules specifically for various configuration levels of site, project, user group and so on. Systems have tried to provide a flexible setting where both predefined and user-defined roles, responsibilities and project/product structures are supported. Systems are set up in a way that context and action types can be used as conditions for access rights. Separate rights policies are defined and implemented for sub-projects versus a parent project, for viewing versus modifying data, and for access to metadata versus content. Users can query a database for classified product (parts and assemblies) and project information mainly based on predefined criteria.

Authoring Product Design Information

Product design data are imported and exported based on predefined workflows determined by the system administrator for each transaction. Design data can be published separately for individual parts and assemblies. BIM Collaboration Hub supported by the Share-A-Space allows exporting the geometric information for each building component as IFC files. Some systems like Windchill even allow selecting categories of object properties to be exported like their geometric representation type (e.g., wireframes, surfaces, etc.). All the reviewed systems support distributed teams to modify and collaborate on many different categories of shared information in non-model format, like bill of materials and enterprise resources. However, only some of the systems, like Creo and CATIA products' family, have integrated parametric 3D modeling engines that enable some level of modification on shared design models within the PLM hub. In the rest of the systems, like Share-A-Space and Agile PLM, users can only modify design models after checking them out of the PLM system using a mixed client/native application environment.

General Management Functions

User activities as well as progress on change requests and applied changes to shared design information are tracked by all the reviewed systems. Published information on multiple versions of product design data are stored in PLM systems and can be retrieved by users based on their access rights.

PLM vendors attempt to facilitate and improve checking and validating designs based on ever increasing complexity of regulations, standards, design intent, and project/enterprise limitations by providing requirement management features. For instance, through ENOVIA Live Validation distributed teams involved in a project can collaboratively review design and analysis data; PTC's ModelCHECK supports model verification by enforcing standards and modification processes; and Teamcenter enables versioning, tracking, and managing changes to requirements and also provides an environmental rules compliance management feature. Approval or rejection of a design is performed according to authorization settings of a system based on usually predefined workflows.

Although often not automated nor efficient, PLM software venders have attempted to provide solutions to manage unstructured data such as design and manufacturing specifications, simulation and analysis results, and production plans and limitations. Their solutions aim to target the unstructured data created within a PLM system as well as data acquired through interfaces with external tools like ERP and CRM solutions and to associate them to product design information to elicit new insights and facilitate decision-making.

Change Management and Synchronization

'Notifications' are event-driven actions; comprehensive PLM packages enable notifications to be triggered both by key events whose rules are predefined in the system, such as release of a design model or meeting project milestones which are assigned automatically, and by ad hoc user-defined events. In the second case, publishers of information can create notifications for identified events and users can subscribe to certain design parts or tasks so as to be notified upon an update.

PLM systems with a higher focus on cPDm provide clash checking tools. For instance, PTC's Creo Elements/Direct Task Agent of PTC and Dassault's Enovia VPM Interference Check and the Clash Server analyze clashes on selected parts of a design based on defined rules for clashes, store and report the results, and track the actions to resolve clashes.

PLM systems have incorporated various methods for detecting and managing changes in design like versioning, timestamps and locking and unlocking different segments of a design model. PLM developers have tried to reduce their dependency on methods that inhibit parallel design and engineering activities. To ensure the consistency of data among distributed teams and that everyone works on the last released data, PLM systems deploy mechanisms to automatically detect and mark outdated design objects and automatically provide design updates to subscribed users. Enovia Designer Central enables a more flexible design process where multiple trees of alternative design revisions can be maintained in the same directory. It not only synchronizes users' product design data with last changes, but also synchronizes product structure with the enterprise Engineering Bill Of Material (EBOM) to facilitate collaborative management of resources (Dassault Systèmes, 2012). PLM systems that incorporate 3D parametric modeling tools can merge individual parts from various engineering domains into a single assembly model for visualization.

Data Visualization and Interoperability

PLM systems with focus on cPDm have added drawing and model visualization capabilities and navigation solutions for design collaboration and usually offer them on the web as well. However, use of 3D parametric modeling to design new parts in the central data server, especially in neutral data formats, is limited; the main focus of products has been on reusing previously designed parts to provide new product assembly configurations through interpolation and extrapolation, not modeling. Model review tools also enable annotation and markup of designs to share various teams' review feedback. In addition to providing an interface for major proprietary CAD file formats either in the main package or through add-on modules, the reviewed PLM solutions also support data interoperability with open neutral data formats like STEP and IGES.

Recent and Future Trends

Review of major PLM solutions and aggregation of recent developments in terms of capabilities and architecture provide us with important insights about future trends that can be used to address shortcomings in collaborative design, engineering and construction in the AEC industry and enhance project performance.

Targeting Small- and Medium-sized Businesses (SMBs) Market. While sharing many of the same PLM requirements with larger enterprises, SMBs have distinguishing characteristics like limited technical support and financial resources, and demand for fast measurable benefits and minimized risk that challenge successful implementation of PLM systems. Hence, PLM solutions have started providing pre-packaged solutions that reduce the need for administration support and include best practices templates. Examples are Enovia SmarTeam, and Teamcenter Express. Considering that a big part of the AEC industry is made up of SMBs, concise architecture, pre-configured processes and lower cost of these systems have the potential to eliminate some of the adoption obstacles and better meet needs of most AEC companies.

Web and the Cloud: Service Delivery Platform Paradigms. Many PLM solution providers have redesigned their offerings to enable delivering essential parts of their services on the web. In the context of delivering web services, PLM vendors first started employing Software as a Service (SaaS) and more recently added Platform as a Service (PaaS) and Infrastructure as a Service (IaaS), where applications and data, computing platforms, and virtual or physical machines are provided as a service, and support the fundamental computing backbone. These three models of offering services are centrally hosted on the cloud over a network. The main benefits are savings for PLM solution users on hardware, software and IT specialist resources during implementation and maintenance of PLM systems and ultimately reducing the total cost of ownership, while benefiting from greater flexibility of application and operating system independent PLM services (Staisch et al., 2012). Autodesk PLM 360 illustrates this trend well. It uses cloud computing to offer PLM services, which makes the product more cost-efficient by benefiting from cloud computing's inherent economy of scale, increases simplicity of deployment and extends PLM capabilities to mobile devices.

BIM tools used in different phases of a building's lifecycle would be leveraged through a distributed collaboration environment when offered as software services and the information backbone of AEC projects will be managed in a virtual data repository which can be provided as a data service (Underwood & Isikdag, 2011).

Service-Oriented Architecture (SOA). The goal of SOA is to provide a multi-tier architectural approach to design and configure a set of wide-reaching business processes that bridge the applications to support interoperability and integration of applications (Hanis & Noller, 2012). Enterprise Service Bus (ESB) provides an enterprise level interoperability backbone for implementation of SOA-based solutions through transportation, orchestration and translation of messages among various applications using Web services standards and interfaces (Papazoglou & Heuvel, 2007). Most of the reviewed PLM systems, have reengineered their system architecture to a SOA to support reusability of processes across applications and to facilitate integration of ERP, MES and CAM systems into the PLM environment (Siemens PLM Software, 2010; CIMdata Inc., 2010).

Social PLM. Web 2.0 and social computing services like wikis and social networking, blogs, tagging and podcasts that are increasingly provided in PLM solutions add real-time collaboration features for distributed design and engineering that enable delivering what can be called "Social PLM". These trends have led to development of Enterprise 2.0 concept (McAfee, 2006) which essentially is a social intranet through which, in the context of PLM solutions, product developers can directly and in real-time collaborate with and capture feedback of their partners, suppliers and customers. Inside an enterprise, dynamic and many times informal and cross-functional virtual teams can better capture unstructured knowledge and share and leverage them in idea generation, product design and problem-solving processes (Bertoni & Chirumalla, 2011).

IMPLEMENTATION OF PLM SOLUTIONS IN THE AEC INDUSTRY

Outlook for Achievements and Synergies

Efficient growth in the role of BIM requires unifying solutions to acquire, manage and make use of information and processes from various project and enterprise level systems and integrate them with building models. PLM solutions can play the role of a unifying platform that captures, integrates and shares the object-based information generated by BIM-based authoring, analysis, and simulation applications.

We could find only a few documented efforts of implementing PLM systems in the AEC companies. A good example is Skanska AB, an international construction company. The company's original goals of implementing a PLM system were to (a) centrally store, manage and retrieve all projects and enterprise information, (b) facilitate cross-functional collaboration among various company groups, (c) share project data not only among internal but also with external stakeholders including partners, suppliers, subcontractors and customers, and (d) better forecast and control costs. The implemented PLM system consolidated company's project portfolio cost data and enabled access to cost data on different levels and based on different criteria such as material, subsystem, component or supplier; leading to better cost planning, easy detection of deviations from planned budget, and more accurate material ordering. BIM as the main source of information for projects and project management processes has not yet been integrated with the Skanska's adopted PLM solution, but is one of the company's major plans for the future (Pöllä, 2010; Koppinen, 2012). This and other case studies show that until now only basic information collection and project and portfolio management capabilities of PLM systems have been adopted and only by a few AEC companies. We believe there is a huge potential for the AEC industry to benefit from integrating PLM technology in their business workflow.

BIM servers are currently being developed to provide a large integrated data- and knowledge-base that can be leveraged not only in design and engineering but also in planning and management of component fabrication, construction operations, and facilities maintenance. To a large degree, existing architectures of PLM platforms can be integrated with BIM servers, leveraging the structured and rich data of embedded building and construction semantics in the object models, for procurement, building product manufacturing and project management. Integration of PLM can facilitate capturing and consolidating information of the current and past projects as well as resources and strategic goals of an enterprise; can enhance efficient decision-making; promote better use of resources and support agile problem-solving. Such a comprehensive information consolidation along with business intelligence tools facilitate uncovering, use and reuse of best practices in design, requirements management and project workflows. Change management features of PLM solutions enable tracking design, fabrication and construction changes in projects and ensuring consistency of working information by different project entities.

Figure 2 illustrates the conceptual model we propose for PLM solutions and BIM servers to integrate their functionality. BIM servers act as a client server where clients both publish and receive building model information. The functions of client servers are grouped based on having the role of publishing or receiving the information. Transactions of publishing data start with the publisher querying models to define and extract a subset of the created information that they want to publish. Routing the published information to the users (receiver clients) that meet the defined access rights is enforced centrally through the developed authorization system for the project and by an enterprise level server that supports the PLM system.

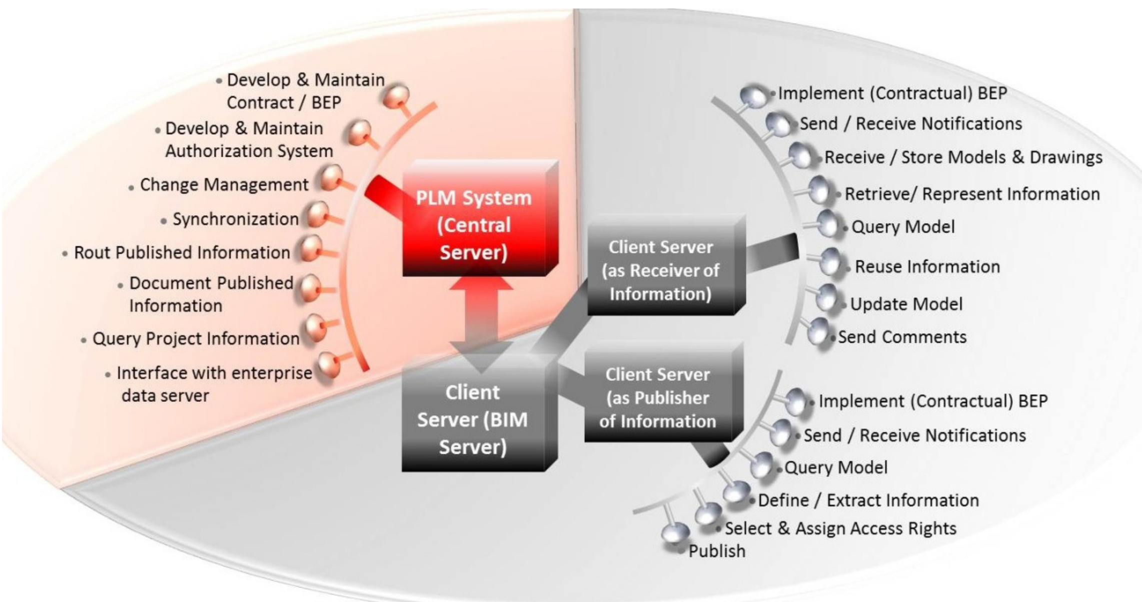

Figure 2 - Proposed conceptual model for integration of BIM and PLM systems

POTENTIAL CHALLENGES

There are important differences between the AEC industry and PLM's current major industry market that require modification and tailoring of some aspects of current PLM technology to achieve successful adoption in the AEC industry. AEC industry is mainly comprised of small and medium sized companies that have different characteristics and demands than large companies; this makes it impossible to implement costly customization-based PLM solutions. Also, AEC projects represent a high variation in project structures and delivery methods which require approaches that enable quick set up of a project with minimal administration requirements, while incrementally addressing required functionality as the project proceeds. Pre-configured PLM packages are a good start but are not enough. AEC-targeted pre-configured solutions together with the cloud-based PLM have the potential to further reduce the ownership cost and the IT expertise needed for the SMB market in the AEC industry.

A large part of design and construction requirements are defined subjectively and sometimes implicitly, represented in an unstructured manner, and frequently change within a project. These characteristics have separated building design from manufacturing and impose limitations in tracking and managing requirements. Further, many building elements are custom-defined design parts and assemblies that create challenges for defining, and managing changes in models at the granularity level of parts and assemblies.

PLM systems are mainly tailored for defining and managing information for discrete units of products. While information units in the fabrication and construction operations of the AEC projects are also made up of discrete parts and assemblies, units of information in design and engineering phases are often dynamically defined model views that are domain-specific partial models and mostly user-defined. This combination and complexity of information transaction units suggest new capabilities to enable tracking changes in the objects of partial models and to synchronize the shared model views.

CONCLUSION

This study provided an overview of the fundamental PLM functionalities and discussed potential benefits of adoption of PLM solutions in the AEC industry. We proposed a conceptual model for functionality integration of PLM solutions and BIM servers. Finally, we identified the differences between the AEC industry and traditional scope of service for PLM solutions. Future research is needed to identify and adopt standards and technologies to develop a standard interface between BIM and PLM systems. Also studies to devise the best practices for adopting PLM systems in the AEC industry are needed.

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