INTEGRATING THREE-DIMENSIONAL PRODUCT MODELS INTO ENGINEERING AND CONSTRUCTION PROJECT INFORMATION PLATFORMS

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ABSTRACT: In the last couple of years, construction companies have invested in the development of engineering and construction project information platforms (ECPIP). ECPIPs store information items in databases on centralized servers and enable project managers to track different versions of and relations between information items. However, most commercial ECPIPs do not support the duality of product and process management that is needed by the construction industry. With the emergence of three dimensional (3D) building information product models to support project management this shortcoming of commercially available systems is becoming increasingly critical. This paper motivates this product-process management problem, addresses a number of emerging solutions, and proposes a conceptual architecture and development process towards ECPIPs.

KEYWORDS: project management, 3D, building information model, communication platforms, product lifecycle management.

1 INTRODUCTION

Surveys conducted by InformationWeek show that professionals in all industries struggle with the problems of how to best store electronic information and how to best retrieve it (McGee, 2007; Rob, 2007). In the construction sector these problems are even more prevailing as construction projects operate in drifting environments (Kreiner, 2007). Information on construction projects changes constantly as (1) client needs are dynamic and misunderstood, (2) engineers need to seek constant feedback from the environment, and (3) different organizations embedded in different social contexts need to interact frequently. This causes a paradox with respect to the exchange and storage of information. On one hand, project information is updated frequently, often tacitly in the heads of the engineers as decision making in drifting environments strongly relies on individual experience (Kreiner, 1995). On the other hand, due to the large number of involved stakeholders, a constant exchange of information is necessary. Additionally, engineers working on construction projects not only need to manage information about the product that needs to be built, but they also need to manage the resources that are needed to build the product, like time, money, materials, or laborers. Computer-based engineering and construction project information platforms (ECPIP) that support construction professionals need to address these two dimensions: product and project management.

In the last couple of years, the construction industry has started to invest in the development and implementation of engineering and construction project information platforms (ECPIP). Currently, these computer platforms either support mainly project management in the areas of cost and schedule control or product management within CAD systems and product lifecycle management platforms (PLM). The advancement of project management tools that use three-dimensional computer models of the construction product however makes a separate implementation of ECPIPs for product and project management undesirable. ECPIPs need to integrate product and process management processes.

This paper introduces the work of a research consortium of construction companies and the Center for Integrated Facility Engineering (CIFE) at Stanford University in California. The consortium was founded in 2005 with the aim to develop such an integrated ECPIP. The first part of this paper briefly assesses the current state of ECPIP-related technologies in the industry. The second part of the paper describes the vision of the consortium about the functionality of ECPIPs in the future. Finally, a research and development approach is introduced that explains how the consortium anticipates to develop and implement ECPIPs that integrate three-dimensional models with project management tools across all important project and business functions.

2 ECPIPs AS A TECHNOLOGY ENTERPRISE ARCHITECTURES FOR THE CONSTRUCTION INDUSTRY

Companies use enterprise architectures to align the implementation of technology to the company's business strategy (Chorafas, 2002: p.3). At the heart of each enterprise architecture is therefore a model of the business. This model represents both data and processes that are used by the employees of the firm during their daily work. Additionally, enterprise architectures define the processes of the company at both the highest levels and lowest levels of the firm (Inmon, 1986: p.2).

In a hierarchically organized company that produces standardized products that have been designed at an earlier point in time these data models and processes can be developed along a one-dimensional axis. Employees at the bottom of the company's hierarchy need to have access to detailed data that can be easily exchanged among the different business units along this one-dimensionally axis. To support higher hierarchical levels, the data can be more and more aggregated as it is passed through middle management to the executive levels of the firm to support strategic decision making.

The business processes of the typical design or construction company cannot be easily organized in such a linear manner, since each company works on multiple unique products simultaneously. A duality of functionality is needed for project-based firms (Ahuja et al., 1994). On one hand the firm needs to organize processes to manage the resources that are needed to accomplish the work on each of the single unique products of the company. On the other hand the products, e.g., the buildings, facilities, and their systems and components, need to be developed by functional specialists that are often shared among the different projects of a company. Therefore, an enterprise architecture for a construction or design company needs to be able to model data and processes along two dimensions: the product management dimension and the project management dimension. However, most commercially existing ECPIPs for the construction sector only support one of these dimensions. The next section gives an overview of these ECPIPs.

3 EXISTING ECPIP SOLUTIONS

As mentioned above, project management platforms traditionally focus on scheduling and budget control. In contrast, product planning and design platforms are concerned with managing the functionalities of a product. Recently, both sides have started to integrate more and more functionalities of the other management function. However, none of the existing commercial platforms can cover the whole range of data and process models across the product and process dimensions. The following two subsections introduce each of the two groups of solutions.

3.1 *Integrated project management platforms*

Traditionally, project management software supports critical path scheduling or cost control on single construction projects. Recently, these project management platforms are integrating scheduling and cost control from a number of different projects to enable firm-wide resource planning. Figure 1 shows a schematic diagram of such a commercial project management platform. These platforms support project-management-specific transactions and operations on a lower level, specifically with respect to cost, schedule and resource management. Additionally, these platforms offer functionality that can aggregate data gathered at the project management level to support high level strategic decisions on an overall project or firm basis. Some of the main vendors of project management platforms are Primavera (http://www.primavera.com), Cando Projects (http://www.candoprojects.com), Microsoft Project (http://office.microsoft.com), MPMM (http://www.mpmm.com), Planisware OPX2 (http://www.planiswareusa.com) and OmniPlan (http://www.omnigroup.com).

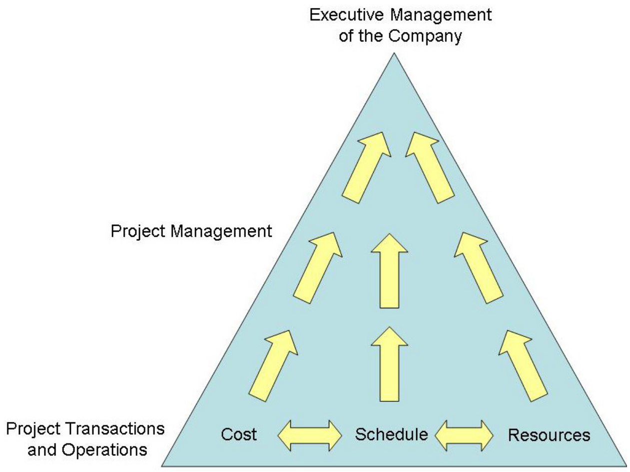

Figure 1. Typical Architecture of a Project Management ECPIP.

Researchers have started to develop architectures to integrate three-dimensional product models into project management ECPIPs to support some business sub-processes (Hajjar, 2000; Caldas, 2003). However, state-of-the-art project management ECPIPs have not yet developed underlying data models to store three-dimensional product data. Typically, product information can currently only be stored in project management platforms as unstructured data in the form of files. Thus aggregating and integrating the information across different product, project, and business functions in the product lifecycle is not easily possible.

3.2 *Product lifecycle management*

Product lifecycle management (PLM) solutions enable management to control the development of a product throughout its lifecycle. Furthermore, PLM solutions enable the cooperation between different companies that work on the development of one product. From a business perspective, PLM solutions allow engineers to manage the status of the development process of a product and, in particular, they enable engineers to manage changes on multi-stakeholder projects (Saaksvuori, 2005: chapter 1). Commercial product lifecycle platforms have been mainly implemented in the manufacturing, automotive, and Aerospace industry. Some of the main PLM solution providers are UGS (http://www.ugs.com), Dassault Systemes (http://www.3ds.com), Oracle (http://www.oracle.com) and SofTech, Inc. (http://www.softech.com). Figure 2 shows a typical architecture of a PLM solution.

One of the main features of PLM solutions is the storage of three-dimensional product data. This enables engineers to view the product from different angles and to cut arbitrary sections through it. In this way the development of the product is supported visually. Information from each of the product development functionalities can be aggregated to support the management of the different product development functions across products. This enables functional managers to reuse design and manufacturing knowledge created during the design of one product for the design of other products. Finally, the product data can also be aggregated to support strategic decision making of the executives of the company within the areas of product development. Lately, PLM solutions are moving towards the integration of project management functionalities. However, these functionalities still remain a small part of PLM platforms. According to Stark (2005: p. 407) project management contributes only about 5% of the functionality of an overall PLM solution.

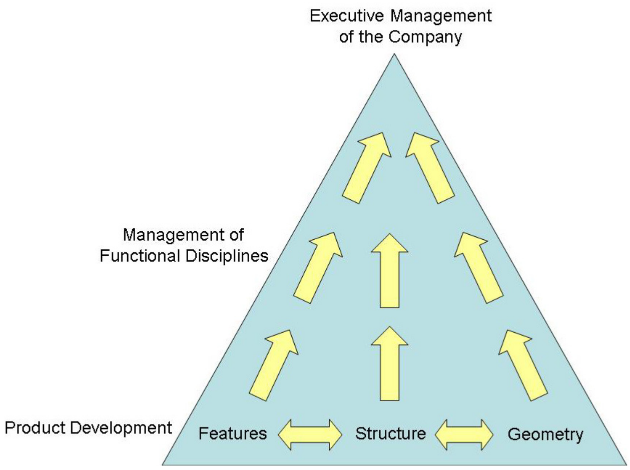

Figure 2. Typical Architecture of a Product Management ECPIP.

In the construction sector, significant research has been conducted in the area of product modeling. For example, researchers have developed the Industry Foundation Classes (IFC), a quasi-standard data model to capture three-dimensional representations and related data of buildings. While most of the existing CAD software applications and some product lifecycle management solutions support the IFC data model, only a few commercially available product analysis applications accept input data in the IFC format. Furthermore, commercially available product management applications for construction, so called building information modeling (BIM) tools, are available to support the development of buildings. Unfortunately, project management functionality within these BIM applications is still only rudimentary. Only some researchers have conducted studies on how to integrate project management functionality with IFCs, especially in the area of change order management (Mao, 2007; Caldas, 2005).

This section showed that there are two different avenues for the development of ECPIP solutions for the construction sector. While in the last years both solution groups have slowly started to integrate features of the other perspective, no commercial platform has been developed so far that is able to support both functional dimensions of the management of design or construction companies completely. Especially, the integration of three-dimensional product models with construction management platforms is a field that will require substantial research and development. Therefore, the Center for Integrated Facility Engineering (CIFE) at Stanford University has founded an ECPIP consortium. In this consortium CIFE is collaborating with a number of construction companies to research the requirements of an ECPIP that integrates three-dimensional product information and product related work processes. The next section describes some of these requirements.

4 CONSTRUCTION OF ECPIPs IN THE FUTURE

The two approaches to implement ECPIPs described above can, in general, if implemented together, cover most of the business processes in the construction industry. However, a simple implementation of one existing system from each approach will result in an environment that is difficult to use and to manage as business processes are modeled in overlapping, redundant, and related systems (Inmon, 1986: p. 5).

One example of an application of three-dimensional models that shows these problems in detail is the use of three-dimensional computer models for the coordination of Mechanical, Electrical, and Plumbing (MEP) systems (Khanzode et al. 2006). The three- dimensional models produced by the MEP and other relevant disciplines are usually combined and managed by product lifecycle management solutions. These product lifecycle solutions track the inputs to the combined three-dimensional model by the contractors that are responsible to design and construct the different sub-systems of the building. Furthermore, they support the automatic detection of clashes between the systems. Additionally, however, a project management system is needed to manage, e.g., the resolution of the clashes. Some of the project management issues that need to be managed during the coordination of MEP systems include the tracking of clashes that the various contractors need to resolve, the management of requests for information of the various stakeholders, and the updating of project budgets and schedules according to change orders that need to be issued. As the systems that practitioners use today are used to support project management do not have direct access to the 3D product modeling system, references to the product are integrated into the project management systems as snapshots, sketches, or references to files. This redundant data storage, in turn, often leads to update problems. For example, 3D product models are not updated with the design information contained in the sketches that are referenced in the project management systems or references that are stored in the project management system reference outdated 3D product model files.

To support such business processes, it is important that construction companies develop a blueprint for a business-based information system. The next section introduces a conceptual architecture for such an ECPIP system and develops a number of high level requirements that such a system should consider.

4.1 *Conceptual architecture*

Figure 3 shows a high-level representation of the required architecture for a business-based system that integrates project and product management. The matrix form of the model represents the two-dimensional data flow that will be necessary for the adequate representation of the business-processes of a design or construction company. Each cross-point within the matrix depicts a functional business process that requires the integration of the product and project management dimensions, such as the MEP coordination process described above. The overall ECPIP system needs to integrate sub-systems that can model the data and business processes that are required for each of these cross-points. Each of the sub-systems needs to exchange data along two dimensions so that the project management and the product management of the adjacent sub-systems can be supported adequately. Additionally, each of the subsystems needs to be able to aggregate data to support higher level project or product business decisions.

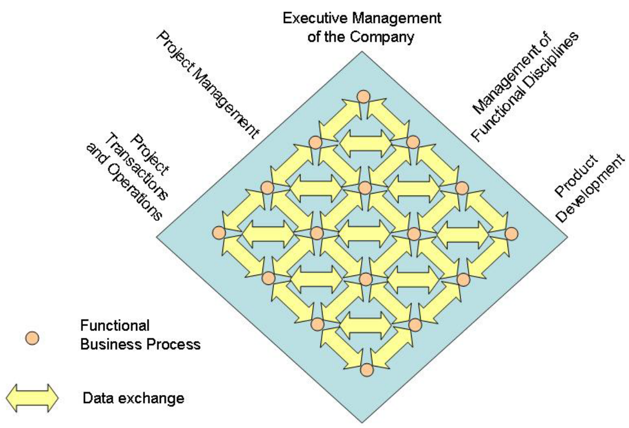

Figure 3. Typical Architecture of an Integrated Product and Project Management ECPIP.

A business-based information system that is based on this architecture will support a design or construction company in its two main functions: project and product management. On the project management side, the system can support project managers during their daily project transactions and operations, project directors to manage resources on a project level, and company executives to manage resources for the overall firm. On the product side, the system can enable engineers to develop unique products while they are simultaneously able to manage specific functional product development disciplines across projects. Finally, the system will enable executive management to make product and project related decisions on an overall firm level.

4.2 *Requirements*

According to Inmon (1986: p.6) a business-based-system-model blueprint needs to

1. Enable system architects to decide which part of the system will be built first (prioritization of activities),
2. Ensure that each part of the system serves the major business purposes and relates to the other sub-systems in an efficient manner (total business requirements),
3. Ensure that each sub-system's processes and data models are invented and built once (reuse of data), and
4. Define clear-cut responsibilities for the various users of the various sub-systems (domain integrity).

A blueprint for an ECPIP system should consider each of these points:

1. The blueprint needs to identify which of the functional business processes on construction projects need to be supported by an integrated project and product management platform. Then system architects need to estimate the respective costs to develop each of these functional sub-processes. In a next step, the architects need to compare the estimates to the predicted benefits each of these functional sub-processes promises if used in practice. According to this cost-benefit analysis the architects have to prioritize the different functional sub-systems so that they can decide which of these systems to implement first.
2. The blueprint needs to specify the data structures and the data transfer processes that are needed to serve each of the functional business processes. Additionally, data interfaces with other functional business processes need to be defined.
3. The blueprint needs to ensure that data structures and processes of functional business processes do not overlap each other for project and product management.
4. The blueprint needs to define organizational positions that are responsible for managing the different business processes. Furthermore, the blueprint needs to define who is responsible for the input and maintenance of data and who needs to be able to update different data items. Additionally, the blueprint needs to outline the organizational positions that will be affected by a change of data in one of the functional business processes.

Ease of use is another important requirement for ECPIP systems. Engineers and project managers on construction projects need to be able to integrate the new supporting systems seamlessly into their daily working processes. In addition to the definition of responsibilities of the various actors mentioned above, this task also requires that the user interfaces of the system are easy to learn and use and are customizable for each of the actors.

5 DEVELOPMENT ROADMAP

We envision the following research process to generate the knowledge needed to develop and implement an ECPIP:

1. ECPIP system engineers need to develop an enhanced understanding of the complex problems that practitioners face during their daily work. Moreover, due to the drifting environment of the construction industry, most of the knowledge on how to solve complex problems is tacit knowledge (Kreiner, 1995). Thus, system developers face the challenging task to capture this tacit knowledge and the experience of the practitioners and convert it into functional business processes.
2. Researchers and system developers need to develop an understanding about the culture in which practitioners

work to solve complex design and construction problems. This is important as the ECPIP system needs to support practitioners when they are making sense of problems and while they are interacting with each other and with disparate product and process data sets. How professionals engage in these two tasks is largely defined by the roles, norms, and values of the professionals and thus by the culture in which they work. The culture also defines the different viewpoints that practitioners use to interpret data during problem solving tasks (Checkland, 1990: p. 49). The ECPIP needs to be able to seamlessly integrate into this culture to gain acceptance among practitioners.

3. After the implementation of an ECPIP system that models the processes existing at the pre-implementation phase, it is most likely that practitioners will change their way of working. We anticipate that practitioners will change existing processes and data models. Additionally, it is most likely that roles, viewpoints to interpret data, norms, and values will change (Checkland, 1990: p. 20). Thus the implemented ECPIP system might model obsolete processes and might not support the new processes efficiently. A constant adaptation of the ECPIP system will be necessary.

One research methodology that is well suited to solve these problems is action research (Baskerville, 1996). Action research is a method for test case research on projects (Yin, 2003; Eisenhardt, 1989). Detailed descriptions of the action research process can be found in Susman (1983), Checkland (1990), or Baskerville (1996). One important characteristic of action research is that practitioners and researchers work closely together throughout the whole research process. The researcher starts doing practical work and the practitioner starts doing research. In this way it is possible to gather and simultaneously verify knowledge about complex processes and determine how practitioners follow these processes in their respective professional culture.

Figure 4 shows the action research process that the ECPIP consortium plans to use during the development of the ECPIP system. In a first step researchers will need to observe processes, the required data models, and the culture on a number of test case projects that implement 3D product models to support construction management processes. From these observations, functional business

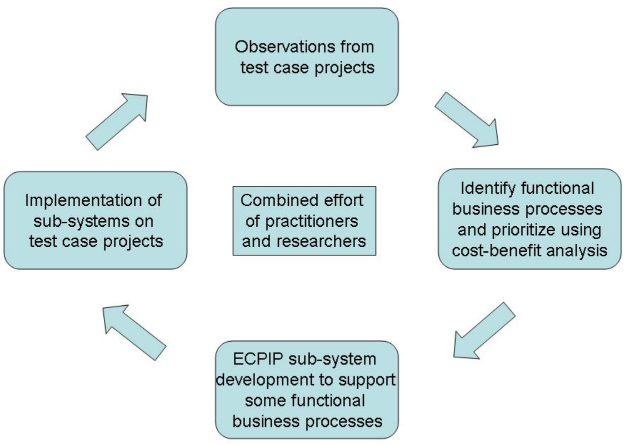

Figure 4. Action Research Cycle for the Development of an ECPIP.

processes that can be supported by an integrated project and product management ECPIP need to be identified. After prioritizing the identified functional business processes using a cost-benefit analysis, system developers need to program sub-systems of an overall ECPIP environment that support the functional business processes that offer the greatest benefits. The developed sub-systems will then be implemented by project teams on case projects, and researchers will engage in another iteration of observations, analyses, development, and implementation.

A number of researchers have already observed how three-dimensional product models have been applied to support project management on construction projects. Some of the latest efforts in this area are, for example, Jongeling and Olofsson's (2007) exploration of how three-dimensional product models support the scheduling of work-flows, Hartmann and Fischer's (2007) exploration of how three-dimensional product models support the constructability review, and Khanzode and colleagues' (2006) exploration of how three-dimensional models can support the coordination of design and construction of mechanical, electrical, and plumbing systems. The ECPIP consortium plans to develop a number of ECPIP sub-systems that will support some of these specific functional business processes. In a next step, the consortium plans to implement these systems on test case projects. The implementation can then be observed and analyzed jointly by researchers and practitioners. Developers can than improve problematic parts of the sub-systems. Concurrently, more sub-systems can be integrated until an ECPIP system has been developed that can support the main project and business processes of construction and design companies.

6 CONCLUSIONS

This paper described one of the major challenges for technology development the construction industry will face in the next couple of years. With the advent of sophisticated three-dimensional product models of facilities that support the project management for construction projects, new ECPIPs for design and construction companies can be developed. These ECPIPs need to support all the functional business processes of practitioners and integrate project and product management. The paper showed that this problem cannot be supported so far by commercially existing software as these applications only support either project management processes or product management processes sufficiently.

The paper introduced a conceptual framework for such ECPIPs that support project and product management processes. This ECPIP framework is able to support functional business processes that need to exchange data into the two dimensions of project and product management. Additionally, the framework is able to aggregate data to support upper management decision making.

To develop ECPIPs that can simultaneous support product and project management it is important for researchers to identify the business and project processes that practitioners use. Additionally, it is important for researchers to integrate the ECPIPs into the culture of the practitioners to foster the acceptance of ECPIPs in practice. Accounting for these requirements, this paper introduced a roadmap for this development that uses an action research methodology. Using this methodology, it should be possible for the developers of the ECPIPs to iteratively program and implement sub-systems that support specific functional business processes. During these iterative implementation steps the action research methodology enables researchers and practitioners to evaluate the efficiency of these sub-processes and improve the subsystems accordingly for the next iteration. In this way, the ECPIP developers can implement and test functional business processes one after the other until an ECPIP has been created that can support the product and project management of a new facility throughout its lifecycle.

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