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ENGINEERING ENVIRONMENT FOR PRODUCT INNOVATION

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ABSTRACT
Product innovations and the competence to innovate are key success factors for any industrial enterprise. When looking inside product development departments, time, cost and quality are generally the predominant goals, which are then targeted by the engineering environment comprised of organizational measures, business processes, methods, and supporting IT systems. Innovation seems to be left the role of an appreciated side-effect. This paper investigates how an engineering environment should be designed in order to foster innovation. What should – against this background – be the interplay between processes, methods and IT?
Product Lifecycle Management (PLM) is a concept often promoted for product development to address both time/cost/quality and innovation. This paper gives advice on how PLM is to be understood and set up to achieve this with best possible results.

Keywords: Engineering environment, PLM, innovation

1 INTRODUCTION
Product innovations and the competence to innovate are key success factors for any industrial enterprise. Studies show a clear correlation between innovation activities and business success – results of a McKinsey global survey showed that high performer companies were more focused on new products or services in their R&D projects – even during the economic crisis in 2009 [1]. Looking inside product development departments, the so-called "magic triangle" of time, costs and quality however often sets the predominant targets – successful engineering is measured by on-time, on-budget delivery to set quality goals. Thus time, costs and quality are the main focus of the business process models applied, the methods used and the supporting IT tools implemented. Together with the engineering organization these processes, methods and IT tools are the components which build the *engineering environment*, in which engineering work is executed [2]. Within this target system, innovation often seems to be left just the role of an (however appreciated) side-effect. It may be encouraged by organizational measures (innovation incentives, workshops or even dedicated departments), it is however not a primary focus of the core product development processes, methods and IT tool setups.

Product Lifecycle Management (PLM) is a concept often promoted for product development to address both time/cost/quality and innovation. Definitions of PLM range from a pure IT systems to a wide strategic and philosophical view. The broader this view, the broader are also the goals associated with the implementation or promotion of "PLM".

In the following chapters we will investigate how an engineering environment should be designed in order to foster innovation in parallel to the established triangle goals. The investigation will be based upon empirical studies from engineering consultancy as well as from leading engineering organizations. The main research questions in this context are:

- *What approaches within these dimensions may promise positive effects on innovation?*
- *What should the interplay between the building blocks of organization, processes, methods and IT be like to foster innovation?*
- *How is PLM to be understood and set up to make this a part of or even the basis for such an engineering environment?*

The outline of this article is as follows. First, we will describe state-of-the-art components of engineering environments with PLM being given a special emphasis. Second, we will give a short overview of innovation and innovation management as it is understood today. Third, we will present challenges and insights derived from empirical studies as well as multiple industrial and consulting projects which focused on setting up innovative engineering environments. In the discussion, we will address the interplay between the components of the engineering environment as well as the question, to what extent PLM could be a lever for innovation. Finally, we will conclude by revisiting the research questions and providing an outlook for future research.

2 ENGINEERING ENVIRONMENTS: ORGANIZATION, PROCESSES, METHODS AND IT

Today engineers and designers are working in highly technology supported environments – driven by mainly economic requirements. Freedom and room for innovation is often limited. Based on this, more and more companies are establishing and increasing their efforts and activities for improving the environment of engineers to enable and support more product innovation.

Observations and leading practices suggest structuring the engineering environment into four main dimensions: Organization, processes, methods and IT [3]. The ratio and order in which these dimensions are addressed vary widely. In the following sections, the four dimensions will first be presented separately. Then, their interrelationships to other dimensions will be elaborated on in order to lead towards conclusions in later chapters regarding what these relationships should look like having an innovation focus in mind.

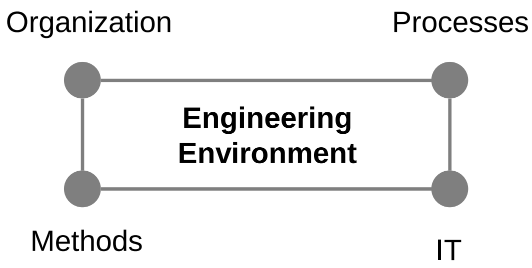

Figure 1: Dimensions of the engineering environment

Product Lifecycle Management (PLM) is a popular strategic management concept for managing products along with their data and has its roots in the area of product engineering and design. However, no commonly agreed definition of PLM exists. PLM concepts are often also structured according to the four dimensions of figure 1. Therefore, this paper will discuss the engineering environment with a special focus on supporting engineering and design work with PLM, and how PLM has to be understood against this background.

2.1 Organization

Engineering organization can be understood either in the state engineering is setup regarding processes and structure or in the way towards that state. Both understandings set the ground for the engineering environment to perform and possibly innovate. Within a product development project the timing and impact of management attention and influence varies and is often not aligned. As described in [4] the curve of “possible impact” (of management) is high in the very early project phases and declines in the later phases. The curve of “effective management impact” is low during the early project phases and reaches two peaks in the later phases – test, implementation and use.

To profit from the “possible impact” in the early phases of a project and to optimize the “effective management impact” at the same time requires the appropriate organizational and procedural preconditions to be established. For this, relevant product information needs to be available through the product lifecycle and across department boundaries, thereby bridging the levels of hierarchy within an organization.

2.2 Processes

Independent of the industry and the type of product a company is selling; processes represent a core competency of any company. An effective and efficient management of business processes is a key success factor not only on a general business level but also for design departments within the design environment.

Beside the involvement of the company's management in the product development process, the utilization and the support of all employees involved in later phases of the product lifecycle are key factors for a successful product innovation process.

These two dimensions of information flow are described in [4] as vertical and horizontal axes within the concept of PLM. In industrial practice the horizontal axis within the PLM solutions is well addressed. Depending on the maturity level of the implemented solution the focus of the PLM capabilities and activities is located around the design departments. On the other side, the vertical axis is currently not as well established. Especially the breakdown of strategic top management information is rarely defined and implemented. Experiences from different companies show that often neither processes nor organizational structures for the aggregation of information – from the lower level of the hierarchy to the higher levels – are in place.

2.3 Methods

Methods fill, support and solidify the respective process steps of the product development process. Generally, a multitude of different methods is applied, each of them implemented for singular or limited process scopes.

What was said for the processes also applies to methods – as methods are also core competencies of a design driven company, they need to be addressed across all lifecycle phases and spanning the entire company hierarchy. Methodical challenges in this context can cover incoherencies or incompatibilities in nomenclature, configuration or variant management approaches, calculation methods (e.g. product cost for an assembly etc.).

2.4 Information Technology

The design environment is influenced and supported by many IT systems. IT solutions support the very early phases of a product development project by documenting and managing product requirements (requirements management). Going forward in the design process, IT tools are used for core design activities (Computer Aided Design - CAD) and for managing all product related data (Product Data Management - PDM) – 20 to 50% of engineering activities are spent on searching and determining the right information, depending on the level of innovation; this shows the importance of managing information for product development projects [5]. Finally, several IT systems are supporting all production processes and after sales activities (Enterprise Resource Planning - ERP). This fragmented IT landscape needs to be coordinated and integrated based on an "Enterprise Architecture" to enable a cross departmental information flow [6].

Of the four dimensions of the engineering environment, IT is probably the one most contentious. The views on IT's value in supporting product development range from it being an important solution approach as such to reach both efficiency and innovation targets (e.g. [7]) to more critical views which reduce it to a poor supporting automation technology (e.g. [8]). Statistical evidence is provided for both views, showing that on the one hand good IT deployment correlates with business success, and on the other hand most IT investments result in failing implementations which do not improve or even worsen efficiency. As a consequence, the relationships of IT to the other dimensions of the engineering environment are controversial. IT advocates would see it as a measure to optimize (and thereby change) existing processes and methods, and to implement industry best practices across all dimensions of the engineering environment. IT critics would on the other hand see IT as the last step, as just one realization technique for formerly defined and optimized processes and methods, in this case however boosting efficiency through automation.

2.5 Implications to PLM

PLM is a strategic management concept for managing products along their lifecycle. Narrow views on PLM often focus just on the IT dimension as a supportive tool for established business processes and methods, then mainly in the form of PDM systems. In a broader understanding however, PLM features all four of the dimensions discussed above, all of them being interlinked and not to be addressed independently. Empirical studies suggest that this second understanding correlates with higher success rates of PLM implementations, and thereby higher business success [9].

In many companies, PLM is already seen as a strategic enabler for product innovation based on ideas and inputs from employees at various points in a product's lifecycle [10]. Moreover, Prendeville and Gupta describe in their article the importance of understanding customers' requirements as a basis for product innovation. Their example gives a flavor of the constraints and conditions for engineering and design work in international companies.

Summarizing this chapter, investigations of the current situation and leading practices of different industries regarding the engineering environment support the following statements:

- Involvement of management levels in product innovation and development processes needs to be supported and ensured.
- Horizontal and vertical integration of information needs to enable end-to-end business processes across all levels of a company's hierarchy.
- Methods applied across the multi-domain engineering environment need to be harmonized.
- An integrated enterprise architecture has to provide appropriate IT capabilities in each phase of the product lifecycle.
- All four dimensions of the product development process are interlinked and to be addressed in a coherent manner.
- PLM may provide a basis for an engineering environment, if it considers all four dimensions of organization, processes, methods and information technology, adequately.

In the following chapter innovation and innovation management will be further elaborated on in order to revisit, confirm and concretize these finding with regards to the creation of innovative engineering environments, afterwards.

3 INNOVATION AND INNOVATION MANAGEMENT

Research literature and leading practice guides provide multiple definitions of innovation and innovation management. As common building blocks of innovation management three phases can be defined: idea generation, idea validation and idea introduction [5, 11, 12], see figure 2.

Figure 2: Building blocks of innovation management

In the idea generation phase new product ideas or product innovation ideas are collected or created based on various sources and methodologies. The sources of innovation are currently a focus of research activities, especially the research question of handling "open innovation" platforms (e.g. ninesigma.com or innocentive.com).

Idea validation, as the next step of innovation management is an important and critical phase. During this phase some innovative ideas might be filtered out based on predefined criteria. There is a risk that an innovation is not passing this "gate" and later on a competitor is successful with the same or similar idea. This might have a big economic impact on the business and the company. For this reason this phase needs to be very structured and well managed.

In case of an idea being selected as a new business opportunity, the idea needs to be introduced and launched in a new or existing product. Very often this phase is seen as the last step within innovation management. The product development process includes all phases of the innovation management and continues as depictured above.

The innovation process described above shows the simplified building blocks of innovation management. Experiences with different industry partners have shown that even simple processes for innovation management are often not defined or established. Even companies which are well-known as innovation leaders are operating on an ad hoc basis when it comes to the management of innovations. The integration of designers and engineers is often very limited and the generation or collection of new product ideas is a privilege for a small group of people within the company.

Looking at innovation from the perspective of the four dimensions of the engineering environment as described above, a lot of work has been done on organizational aspects of innovation. Innovation management processes are well described, and innovation methods exist in a wide variety. The relationship between innovation and IT has however not that clearly been described. IT suppliers generally claim their tools to have significant innovation enabling capabilities; this especially refers to CAD and PDM systems. Empirical studies are brought forward to prove such relationships. Reviewing the results more critically the interpretation gets less clear; it might as well be, that innovative companies are better in deploying IT, or that there is a third factors boosting both innovation and IT deployment success.

Again, this discussion shows the importance of looking at engineering environments and PLM as a whole, with IT in each case being just one factor out of four. The following chapters will do this with regards to the goal of fostering innovation.

4 WAYS TOWARDS INNOVATIVE ENGINEERING ENVIRONMENTS

Engineering environments have changed over the past years quite heavily. While continuing this development of engineering and design work and methodologies, based on the outlined investigations and experiences the following areas should be considered.

In line with the structure of chapter 2, considerations of each of the four dimensions will be presented separately. First, in chapter 5, the implications regarding the interrelationships of the dimensions will be elaborated on, and PLM, its role and design against the background of innovation will be discussed.

4.1 Organization

Companies need to establish appropriate organizational structures to support a company-wide innovation management within a company-embracing innovation culture. Generic academic and pragmatic rules for innovation management can be found in well-known publications (e.g. [5, 11, 12]). From consulting experience one highly critical factor is the involvement of the top management for this cultural and organizational change.

4.2 Processes

Processes have to be honored as not something “just there”, but as one key competence that enables industrial companies to perform [7]. Innovation needs a clear process basis, with possibilities also to initiate process change. Therefore, clear process responsibility and governance has to be established and empowered on an organizational level.

End-to-end process documentation is one key success factor to enable an effective and efficient engineering environment. Beside the documentation of business processes, the capability of process management needs to be established. This capability ensures that on the one hand only real-life processes are documented and on the other hand agreed and documented processes come alive. The maintenance of process documentation needs to be considered and managed as well. Moreover, processes bridging a company’s hierarchy and crossing departments need to be defined, agreed upon and documented. Innovation management processes are well researched, described and published, however they are not consistently applied, as described in chapter 3.

From this description it is obvious that processes build on an organizational foundation, treating these two dimensions of the engineering environment as a priority.

4.3 Methods

Companywide processes require common or at least harmonized methods. This is especially true in cross-x (with x representing domain, lifecycle and enterprise dimensions) engineering organizations. Bergsjö et al. [6] elaborates on cross-x methods integration on the examples of configuration management and change management, which represent key methods in any complex engineering environment. To achieve this harmonization a cross-functional and cross-departmental team needs to be established and empowered to govern and define these methods. This topic is often underestimated and needs top management involvement as well.

This description shows that processes build the framework for the deployment of methods, thereby adding methods to the order within the engineering environment dimensions described above.

4.4 IT

Information technology's role is to support the defined processes and methods. Therefore, there has to be a fit between IT concepts and solutions on the one side and processes and methods on the other side. Taking processes and methods for granted, well-fitting IT tools would have to be selected or customized. Taking IT solutions for granted, processes and methods would have to be adapted to the system-inherent (supposed-to-be) best practices. This fits to the management-popular approach of "no customizations", but may downplay the importance of distinguished processes and methods, which may be keys to company-specific innovation-oriented engineering environments. To complete the discussed order of the disciplines of the engineering environment, this paper will follow the former, subordinated understanding of the IT dimension.

In any case, end-to-end processes and common methods require an integrated enterprise IT architecture; based on this a companywide product data backbone has to be implemented [6]. Existing IT landscapes need to be considered while planning and setting up the approach for an integrated enterprise architecture.

As a basis for such an architecture, a common enterprise-wide harmonized product information model is required to enable integration from a granular level, upwards. Only based on a sound informational foundation across vertical and horizontal organizational borders, an innovation-centric engineering environment can be erected. Based on the understanding of IT promoted in this paper, it is clear that this information model is not to be misunderstood as an IT-focused data model; it is to be established as an integrated approach with IT being just the enabling realization dimension. In the following, this model will be referred to as the *Enterprise Architecture Product Information Model* (EAPIM), which is in core focus of ongoing and future research work. This paper discusses the environment of the EAPIM. Based on current findings of the ongoing research underlying this paper, further work needs to be done to elaborate the requirements for and elements of the EAPIM.

The EAPIM needs to reflect all relevant information for different company hierarchy levels (vertical dimension) across the product lifecycle (horizontal dimensions), see figure 3. It has to be based on an all-integrating product data backbone incorporating information about products, processes and production resources, with PDM and ERP being main system components. The information model needs to be able to describe the business requirements of all relevant departments and groups within a company in a system neutral way to be able to reflect information from all four dimensions: organization, processes, methods and IT data.

Industrial experiences show on the one hand that such an all-embracing product information model is difficult to establish and its necessity therefore often neglected. On the other hand, consulting experiences shows the importance of such a model for the success of engineering IT deployment. One key part of the research activities is therefore to determine a low-as-necessary, but high-as-possible level of granularity and extent in order to support the process and method goals as required with a manageable level of information complexity.

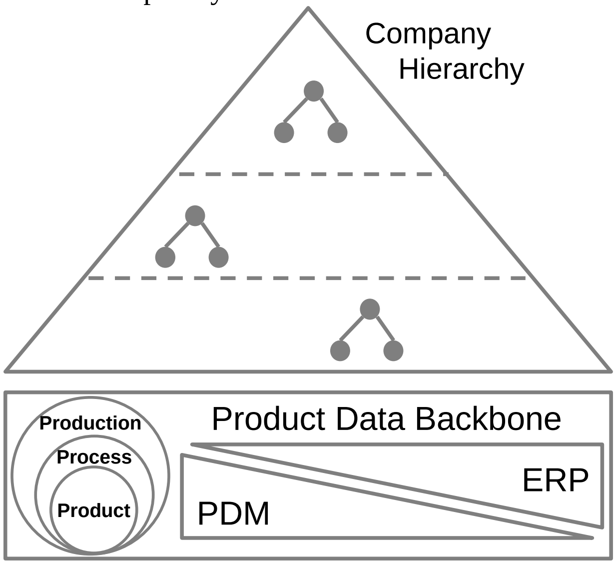

Figure 3: Enterprise Architecture Product Information Model

As a basis for further research activities the approach for documenting the new information model had to be defined. Based on experiences in process and workflow documentation a semi-formal approach will be used. Beside typical process documentation elements – process steps, roles, departments, triggers, inputs and outputs – the information model will include design information as well as process and production information [13].

One main objective of the new approach will be to target core product information and context information. Currently existing approaches and frameworks need further investigation regarding their usage in terms of a horizontal and vertical integration across the entire product lifecycle. An example and potential starting point for ongoing research activities is the “Engineering Object” concept as described in [14].

5 DISCUSSION

In chapter 4, considerations regarding the innovation-oriented design of the dimensions of the engineering environment have been discussed. They result from empirical observations from industrial and consultancy projects. Hints have already been given regarding the interplay of the four dimensions of the organization, processes, methods and IT. This interplay will be further elaborated on in the following chapter. Afterwards, the question regarding the design of PLM will be revisited in order to define conditions, how PLM can be made a lever for innovation within the engineering environment.

5.1 Organization, Process, Methods and IT interplay

Regarding product innovation the dimensions organization, processes and methods are well elaborated and addressed in research literature as well as partially also in innovation-driven companies. At the same time the dimension of information technology is not covered consistently at a comparable level – neither in literature nor in industrial practice.

Experiences within different global companies show that not only the four dimensions themselves are relevant but also the order and priority in which they are addressed within a company is critical. Several examples exist where companies intended to upgrade or replace their existing IT landscape in the area of product development. Because of the way however the projects were set up and positioned within the company they became pure IT-driven projects. Thus the other three dimensions were not in focus of the activities so the range of possible improvements was quite limited, standing against significant costs for IT implementation and rollout.

As a contrast, other PLM projects were also set up to replace the current IT solution, but to concurrently (or even beforehand) also revise and improve the existing product development processes and methods according to leading industry practice. Although giving a positive example regarding process-orientation of IT projects, these projects underestimated the impact and opportunities of the missing organizational dimension.

These two simplified examples show the relevance of the four dimensions for an engineering environment. Based on research and industry experiences in the area of product innovation and development they are – as a whole – to be seen as critical and crucial for process improvement and IT implementation projects. As currently a high percentage (84% acc. to [15]) of PLM programs are not successful new and holistic approaches are needed.

5.2 PLM as a lever

As described earlier, PLM is a strategic concept for product development featuring the same main building blocks: organization, processes, methods and IT. Therefore, this paper proposes to use PLM as a lever in the product innovation phase and as an underlying basis for the engineering environment. Preconditions are a defined interplay of all four dimensions, the right priority of these building blocks as described above and a broad understanding of PLM, accordingly. In combination with an optimized and comprehensive information representation (e.g. supported by EAPIM) PLM may enable companies to achieve even higher objectives in the area of product innovation.

Figure 4 depicts the principles that are required to establish an engineering environment that enables and supports innovation. From the as-is situation, where PLM is generally limited mainly to the core product structure, thereby leaving the innovation oriented early phases outside, a to-be concept has to be developed in a way that all product determining and describing structures – especially in the early phases – are made compatible, formalized within the system landscape and interlinked. This integration has to be established across the organization, methods, process and IT dimension.

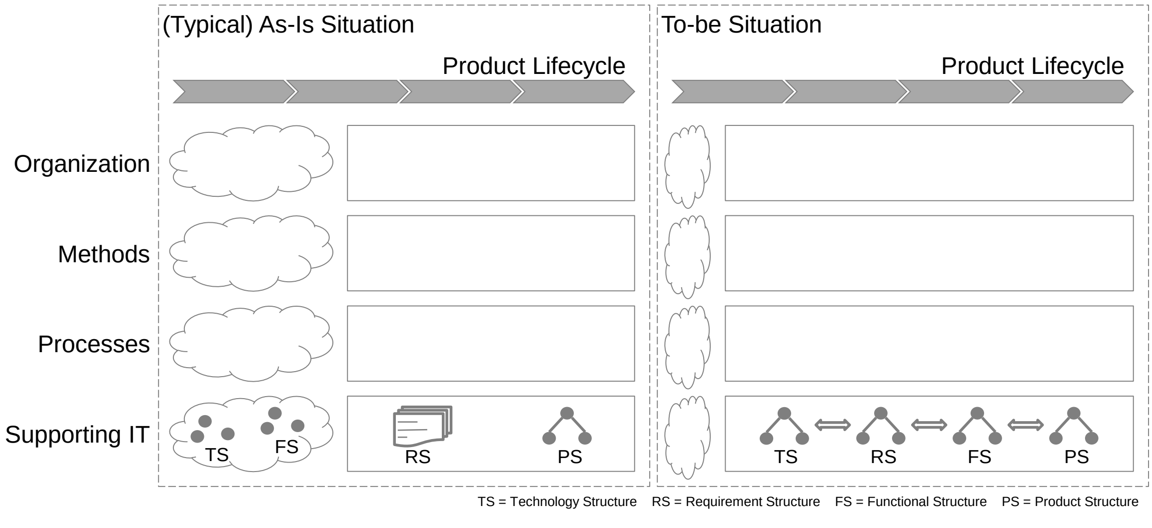

Figure 4: As-Is and To-be Situation of an Engineering Environment

The current situation in many companies can be described as “flexible” or “undefined” in the very early phase of the product lifecycle. This applies to all four dimensions – even literature and leading practice currently provide a variety of guidelines for the supporting innovation management in the areas of organization, methods and processes. To a certain level this flexibility or freedom is required to enable innovation.

Taking the assumption, that all the current existing knowledge regarding these three dimensions is widely established, the missing building block is the supporting IT in the early (i.e. innovation) phases. The intention of IT in that respect would be to support the business processes and provide the right information at the right time with the right level of quality. With this understanding in mind, the concept of PLM can be one lever for an innovative Engineering Environment.

Existing software products for innovation management or idea management are dealing with innovations and ideas as separate items described by a prose text. Moreover, the maturity of the innovations or ideas is tracked via the software by displaying the phase of the innovation process that the item is in. These standalone software solutions do however not provide the capability to interact and keep track with various sources of product information that are involved over the entire product lifecycle. Based on experiences and the intent of the PLM concept, similarities can be seen and adapted to develop an integrated representation of information – starting with ideas and innovations – across all phases of the product lifecycle.

In Summary, an integrated concept of PLM across all four dimensions is a promising approach to developing engineering environments that enable product innovation. The underlying understanding of PLM is however crucial. The representation of information in the very early phase of the product lifecycle was identified as a major area for further research. Information representation is required not in terms of a data model for programming the final software solution but in terms of the information model (e.g. EAPIM) required to reflect and communicate business process requirements around product and process information.

6 CONCLUSIONS AND OUTLOOK

In this paper, the relation of the engineering environment, which is comprised of organizational, process-related, methodical and information technological elements, and the ability to innovate was discussed. It was pointed out that all four dimensions are interrelated with innovation, and that especially the interplay of all four dimensions is crucial for successful, innovative engineering. Dimension-wise, requirements regarding the organizational involvement of management levels, the integration and harmonization of business processes and methods and the underlying IT capabilities were elaborated on.

Product lifecycle management (PLM) has been discussed as a strategic business approach potentially providing a basis for an engineering environment, as it, in a comprehensive understanding, also comprises the four dimensions of organization, processes, methods and information technology.

Revisiting the research questions from chapter 1, first answers can be given as follows:

- While organizational, process-related and methodical concepts for innovation management and innovation fostering are widely researched and applied, innovation-oriented IT concepts are not that well established. Especially an IT-based foundation in the form of an all-comprising information model is still lacking. Hints towards the development of such an Enterprise Architecture Product Information Model (EAPIM) were given. Essentially, innovation-oriented forms of organization, processes and methods need to be established, first. Then, an appropriate information model can be determined, which reflects all relevant information – as described in the EAPIM.
- The interplay between the dimensions of the engineering environment is crucial and should follow a logic of processes building on an organizational foundation, methods supporting these processes, and IT enabling both methods and processes.
- PLM in this context is to be understood as an integrated concept with organizational, process-related, methodical and information technological elements to be successfully implemented and deployed. Addressing PLM with just singular or wrongly-ordered approaches may lead to it being less successful in terms of the time/cost/quality and innovation goals.

This paper however constitutes just a starting point and opens up requirements for further research. Main lines followed will be the further detailing of the EAPIM, its integration with all dimensions of the engineering environment and, finally, its application within consulting and reengineering projects focusing on setting up innovative engineering environments.

This comprising a bottom-up approach to the design of engineering environments, it will be interesting to be correlated with top-down approaches which address innovation coming from more engineering paradigm or innovation culture oriented directions.

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