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ARE COMPANIES READY FOR THE REVOLUTION IN DESIGN – MODELLING MATURITY FOR VIRTUAL PROTOTYPING

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ABSTRACT

Companies are meeting growing demands for readiness to respond rapidly to changes from the outside world. Companies actively manage and develop their competences by applying new technologies and methodologies such as virtual prototyping (VP). Nevertheless, no general, structured guidelines for VP implementation are available due to novelty of the use of virtual reality technologies in machine industry.

The purpose of our research was to improve the use of VP in companies. In this paper, we describe two company cases from the machine industry that are implementing VP for everyday use. During the research, it became clear that the companies had quite intuitive ways for the VP implementation, and they experienced many challenges. This paper describes how companies can improve VP implementation in a more structured way using the virtual prototyping implementation maturity model (VIRMA). VIRMA supports companies in improving their adaptations of VP and benefitting earlier from VP use in design.

Keywords: design process, early design phases, virtual reality, virtual prototyping, maturity

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1 INTRODUCTION

Companies are meeting growing demands for readiness to respond rapidly to changes from the outside world. Companies actively manage and develop their competences by applying new technologies and methodologies such as virtual prototyping (VP). Wang (2002) defines VP as: 'a construction and testing of a virtual prototype. Virtual prototype is a computer simulation of a physical product that can be presented, analysed, and tested from concerned product life-cycle aspects such as design/engineering, manufacturing, service, and recycling as if on a real physical model.' Unfortunately, the potential of VP (and exploited virtual reality [VR] technology) in product design has still not been fully adopted in practice in industry. Based on a literature review (Leino and Riitahuhta, 2012), which summarizes the recent progress on virtual-engineering-based, human-centred design and product lifecycle management, the main gaps relate to a lack of practical and adapted implementations of human-centred design, integration of virtual engineering into product processes, bi-directional data and information flow between virtual engineering applications and data management systems (product data management [PDM] / product lifecycle management [PLM]), and a lack of sufficient methods, tools and infrastructure for managing company content and knowledge. It claims to be a means of assessing a company's readiness regarding the current overall design collaboration competences to identify fundamental and urgent development needs in order to choose where to invest in its future engineering capability.

Maturity models are widely used in process improvement since they offer an effective but simple way to measure the quality and respective maturity levels of processes and their overall innovation and engineering competences. Maturity models are normative, conceptual models to assess as-is situations to outline foreseeable, consistent and claimed evolution paths towards maturity or readiness as reference models (Wendler 2012, Becker et al. 2009 and 2010, Jansson 2011, Cleven 2011, Cleven et al. 2012). Becker et al. (2009) define the maturity model as follows: 'A maturity model consists of a sequence of maturity levels for a class of objects. It represents an anticipated, desired, or typical evolution path of these objects shaped as discrete stages.'

The recent maturity model research field has been heavily dominated by software measurement and development, software engineering domains and business process (BPM) management. The cases have been on, for example, the Capability Maturity Model (CMM) and CMM Integration (CMMI), the IT Performance Measurement Maturity Model (ITPM) or the Business Process Management Maturity (BPMM) (Wendler 2012, Becker et al. 2009, Cleven et al. 2012).

Relevant issues have included key performance indicators and process/corporate performance management, and the focus has been on process capability assessment and improvement, and on the implementation of BPM systems, though not on the implementation of the engineering software, especially the design-related systems (software and hardware) at the end-user companies. It is obvious, however, that manufacturing and service organizations have been the early adopters of maturity models, and the focus has been on the implementation of enterprise resource planning systems but not the implementation of design systems.

The purpose of our research was to improve the use of VP in companies. In this paper, we describe two company cases from the machine industry that are implementing VP for everyday use. During the research, it became clear that the companies had quite intuitive ways for the VP implementation, and they experienced many challenges. Moreover, no general, structured guidelines for VP implementation are available. This paper describes how companies can improve VP implementation in a more structured way using the virtual prototyping implementation maturity model (VIRMA). VP implementation was investigated in the companies and the challenges listed. The first model of VIRMA was described and the development iterations were started in the case companies. The initial results of the use of VIRMA are presented and some further developments highlighted.

2 DEVELOPMENT OF A VIRTUAL PROTOTYPING IMPLEMENTATION MATURITY MODEL

2.1 Background

The development of a VIRMA was based on an inductive approach and action research method. The approach 'Procedure model for developing maturity models' (Becker et al. 2009) was applied to the development of the VIRMA. Due to the action research, the development process was not followed literally, as it is in Becker et al. (2009) but used as a formative tool to construct the maturity model. During the research into the companies' VP implementation, several challenges and the lack of a structured implementation process were recognized. The main goal of developing this maturity model was to support the companies in their systematic VP implementation, improve their effectiveness of using VP and increase their awareness that VP is not only the use of VR technologies but also includes other elements, such as organizational, business and human resources aspects. Furthermore, it is particularly suitable for monitoring the companies' development rather than as a benchmark for assessing different companies for an equivalent comparison. Maturity models that explicitly address VP implementation could not be identified.

There were two company cases (Company A and Company B) for the VP implementation measurements. In order to characterize this research and the case studies, the 'Faceted Classification Approach' of McMahon (2012) was applied. The time episode under study took several months, and the research concerned actors from several functions and stakeholder groups within the companies. The interesting parts of the product life were the concept design and requirements formulation phases. The dimension of the issues of concern was comparatively large. The nature of the artefacts focus was one of complex interconnected human-machine systems. The degree of originality of the design application was intended for radical innovations rather than adaptive design. The degree of abstraction used in the design related mainly to visual computer simulations in virtual environments (VEs) simulators. The research approach included action research, observation, survey and interview.

During the research, there were several workshops at the two companies to identify the current level of the design processes and the VR technology used. Structured and informal interviews were used during the workshops. After describing the current status of the processes they were modelled further iteratively. Functional process diagrams (swim lanes) were used for process modelling. One company also had a simulation game that evaluated the proposed VP process model and further defined inputs/outputs. Ideas and comments were also gathered during the simulation game. Lifecycle stakeholders from design; production; purchase; supply; logistics; commissioning; operation; maintenance; customers; end-users; and business owners, such as product managers, project leaders and support process owners, e.g. CAE, PLM, IT, management, were present at the simulation game meeting. One joint benchmarking session for the companies was also held. During the session, the companies presented their current situation of applying VR technology and process development. Some future visions were also shown.

During the workshops, many challenges were detected and listed in the following categories: (1) human, (2) technology and (3) process. Human related challenges are: (1) users' attitudes towards VR technology (user acceptance, fears, interests), (2) culture changes needs time, (3) informing and involving all people in the company is difficult (when people see the benefits, they will be more adaptable), and (4) lack of resources. Technology related challenges are: (1) model updates; there is a need to convert models more easily and reduce costs, (2) creditability; it will be gained only 'case by case', and (3) interaction technologies (e.g. eye-tracking, haptics, HMD). Process related challenges are: (1) lack of a systematic approach to concept design, (2) lack of knowledge of how to manage and measure concept design, (3) handling networks, (4) knowing how to use VP (there is a need for instructions on when to use VP and what to evaluate), and (5) no clear plan on how to implement VP.

2.2 Maturity model for virtual prototyping implementation in companies

The categories described in the maturity model are based on the company cases and challenges presented here, our previous experience, findings from literature, and approaches/theories such as the value chain model from Porter (1985), the design theory (Hubka and Eder 1988) and relevant guideline fundamentals regarding systems engineering (ISO/IEC 15288, 2008). Moreover, Ameri and Dutta's (2005) definition of PLM as a business solution that integrates organizations, processes, methods, models, IT tools and product-related information was used. The categories are (1) understanding business impacts/opportunities, (2) product process including lifecycle, (3) virtual prototyping process, (4) virtual prototyping technology, (5) enterprise infrastructure, (6) human resources and (7) enterprise culture and organization. For every category, there is quality assurance to ensure that the maturity levels attained are not based only on, for example, existing technology but are also fit for the purpose.

Table 1. Virtual prototyping implementation maturity model (VIRMA)

	Unstructured	Repeatable but intuitive	Defined	Managed and measurable	Optimal
Understanding business impacts/ opportunities	No connection to business value	Few successful cases implemented	Benefits for the company defined	Strategic goals and roadmap defined; benefits monitored, evaluated and measured	Fully known benefits and business impacts; value for business recognized; continuous process development
Product process including lifecycle	No visible process	Few processes recognizable	High-level process definitions	Processes implemented and defined in detail	Methods and tools for processes defined
Virtual Prototyping (VP) process	VP has no connection to the design processes	VP is used intuitively as part of the design process	The use of VP has been described in the company processes	The use of VP as part of the processes is managed and the benefits can be measured	Processes are refined and iterated to the level of best practice; the methods and use of VP are embedded in daily the practices
	Basic components	Repeatable	Usable	Flexible	Optimal
Virtual Prototyping technology	2D or simple 3D visualization systems	Low-end VP system	Tailored VP system for company needs	Flexible VP system that supports several design purposes	Flexible VP system that fully supports all design needs
Enterprise Infrastructure	Poor facilities for VP available; case-specific modelling	Dedicated, isolated facilities for VP; one-directional model pipeline	Modules of infrastructure have been defined; most of them have been implemented; bi-directional model pipeline exists	Modules of infrastructure are implemented and measured; implemented efficient bi-directional model pipeline	Perfect and dynamic infrastructure for VP; includes information modelling and integration with PDM/PLM
	Non-existent	Policy	Knowledge	Active	Optimal
Human resources	No one has been nominated to be responsible for the VE system	One person is responsible for the VE system	One or two persons is/are responsible for the system; designers know the system	A few persons are responsible for the use of the system; designers (and others) know how to apply the system to the design and their work	A few persons are responsible who can use the system; the whole company knows how to use it in design
Enterprise culture and organization	Negative attitude towards VP; benefits	Some people see the potential and use the	The culture is positive and the potential of VP	The VP system and benefits are understood;	The whole company sees the potential

	hard to describe	system	is seen; The company is actively marketing the system; organizational change management is defined	active culture of knowledge creation around VP	and benefits and also promotes the use outside the company; the value network model is defined

All categories can be classified based on a general scale of one to five of maturity levels (Table 1). The basic maturity levels of the VIRMA model are based on the general maturity models, such as CMM and CMMI. The maturity levels are defined from unstructured/reactive/non-existent to an optimal/flexible/proactive level even though different designations are used for the categories. Basically, this means that there are categories from the simple use of VR technology in one type of case to multi-purpose use (e.g. for requirement definitions, sketching concepts, reviewing design) in well-managed complex systems (e.g. networks). The maturity levels for business and processes are (1) unstructured, (2) repeatable but intuitive, (3) defined, (4) managed and measurable, and (5) optimal. Technology and infrastructure have maturities called: (1) basic components, (2) repeatable, (3) usable, (4) flexible, and (5) optimal. For human resources and organization, the maturity levels are (1) non-existent, (2) policy, (3) knowledge, (4) active, and (5) optimal.

2.3 Company maturity level

Currently, Company A has adopted and implemented a virtual simulator of VP (Figure 1). It is an immersive, virtual environment in which projectors are directed at the four walls of a room-sized cube. The company bought the equipment and installation from the simulator provider company. All model updates still come from the simulator company. Current VP use has not yet been implemented at the detailed process or methodology level. The process has been defined as a high-level, stage-gate process, which is followed in new product development (NPD) projects. Currently, there is not a specific process definition for using VP. The aim is also to integrate VP into the NPD process.

Figure 1. Virtual environment in Company A

In the case study of Company A, VP was applied at the concept design phase. It was used to capture end-user (operator) needs and for the validation of the requirements specifications. The concept of the cabin is designed by mechanical engineering. The concept design of cabins includes alternative layouts, main dimensions, user interfaces, control devices and materials. The detailed design is done separately. The cabin dimensions are highly limited by the working environment and ergonomic/safety standards. The company follows systems engineering processes in automation software engineering but not really in mechanics or mechatronics system design. The concept documentation includes

definitions of layout and functions. After the concept decision, industrial designers take care of the form.
Company A is very experienced at using multi-body system (MBS) dynamics simulation in engineering, but the virtual environments and simulators are a new technology for them. The MBS simulation is used in concept design to compare alternative concepts and to optimize tasks (hydraulics-mechanics). Model and simulation data management is based on file folders. Figure 2 shows the results of Company A's maturity level measurements when implementing VP. It shows that the company is starting to take further steps in all areas but that it is still at quite an average level.
The understanding of business benefits as well as impacts and opportunities related to virtual environments is just beginning to grow because of the short period of experience. The approach of the implementation is based on pilots in product design and development departments. The enterprise culture and infrastructure have therefore not yet reached higher maturity levels. The awareness of the need to connect VP to product processes and data management grew during the pilots projects.

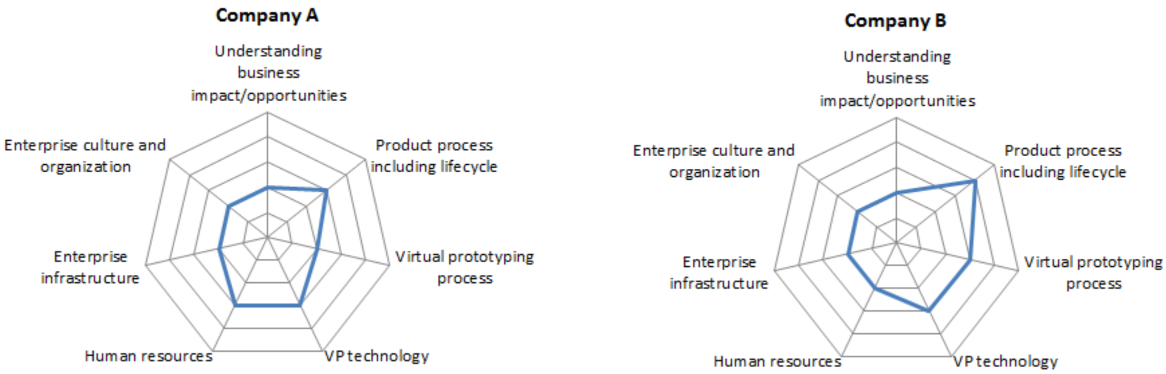

Figure 2. Virtual prototyping maturity level of Company A and Company B

Company B is currently implementing and developing new concept design processes as part of the PLM implementation. It has well-defined NPD processes, and the use of the VP integration is described in part in them. The concept design is emphasized in the new process definition. The process implementation has a top-down approach, i.e. the higher level process is implanted first, and it then goes towards more detailed definitions. As part of the process development, the VP project is also ongoing. The processes are at company corporation level, but the research case, in practice, focuses on developing the VP environment at a new facility into which it is moving.
Currently, simulators (virtual environments, VEs) are not used systematically as part of any process. Concept design is a separated process in which VE is the media for supporting communications within design reviews and requirements validation. Model-based systems engineering is an active topic at the company. Nevertheless, the interest in modelling and simulation has mainly focused on internal product properties, such as function and strength. MBS and other CAE tools have been used extensively there. However, in this research 'external' product properties (like ergonomics and safety) are the most interesting because of the focus on the concepts of user interfaces, which is a new approach for the company. Another question that has arisen is what is needed at the level of the product specifications and models for evaluating a concept.
Company B has a good level of maturity for implementing VP at the product process level (Figure 2) because it has been adopted in the PLM implementation. Currently, the company is implementing a new VR technology system that will improve the level of maturity in this area. The maturity of business understanding, cultural and organizational as well as infrastructure and human resources issues, is at a lower level because of the stronger emphasis on pilots in product design and at the development department. There is already awareness of the need to expand VP within all aspects of enterprise.

3 DISCUSSION

Figure 2 is a good illustration of the situation in the companies during the VP implementation. It can direct the development work in companies to help them gain earlier benefits from the use of VP in

design. It also highlights seven categories that are directly connected to the VP implementation. A VIRMA has been developed during the research into the two company cases' VP implementation. The goal of the research was to improve the use of VP in industry, and the VIRMA was developed alongside this.
The two industry cases differed from each other: one company had installed and used the virtual environments system first and then begun to develop the processes further. The other company had done it mostly vice versa: first it had made the process changes at the theoretical level (not yet in practice) to describe how to use VP in concept design and then it had adopted the VR technology system. The maturity model approach for measuring the implementation level is good because it does not take a stance on which approach is best, only what the level of maturity is.
During the research, the companies' motivation for the VP adaptation was discovered. The companies saw that rapid and agile concept modelling and simulation incorporated with verification and need/requirement validation was needed. Early feedback on the design was seen as important, and they agreed that this led to better quality products and shorter time to market. The VP also makes more radical concept experiments and 'what if' questions possible. The companies also saw Systems Engineering and Requirements Engineering disciplines that should be regarded here.
The companies felt that some competitors were further ahead in applying new technologies and they wanted to narrow the gap. Moreover, it can be said that there is a certain 'wow' factor when talking about virtual reality technology, and this affects the companies' images. An eagerness to learn more and to go forward in the R&D sector also motivates companies. The aim is better use of 3D data.
The companies could see the same benefits of using VR technology in design as listed in Aromaa et al. (2012). They also thought that VP helped with the complexity of products and in perceiving modularity. The need for large real-time multi-discipline (mechanics, control, hydraulics, energy, environment, etc.) dynamics simulations in which users were involved was also recognized. The use of VP makes good design possible and therefore improves value for the customer.
Based on Becker et al. (2009), several iterations are needed when developing maturity models. The initial iterations for VIRMA were made during this research but several iterations are still needed, especially in developing quality assurance and measurement methods.

4 CONCLUSIONS

This paper describes a virtual prototyping implementation of a maturity model (VIRMA) for implementing VP into companies' design, especially in the mobile machine domain. It also shows the companies' maturity levels and lists possible challenges during the implementation. VIRMA consists of the following categories: (1) understanding business impacts/opportunities, (2) the product process including the lifecycle, (3) the virtual prototyping process, (4) virtual prototyping technology, (5) enterprise infrastructure, (6) human resources, and (7) enterprise culture and organization. The maturity of the companies seemed to be at a level at which there was an interest and capability to adapt to the new technology. The technology implementation is therefore not seen as a big challenge, but the rapid and agile use of it is a concern. The main challenge was the change of processes and the way of working. Three main types of challenges were recognized: human, technology and process related.
Currently, the use of VP systems in companies in the machine industry is quite novel, and there is therefore not much guidance or many processes for its implementation. VIRMA supports companies in improving their adaptations of VP and benefitting earlier from VP use in design. Using VIRMA, it is easy to measure the current maturity level in companies and to define further development steps for the VP implementation. VIRMA was defined during the research in two company cases. It is still under development and needs more iteration cycles, testing in several companies and validation.
However, not many companies in this area use VP yet.

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