Editorial: How are product development and engineering processes enhanced by involving research?

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There was a time when product designers and engineers could solve their design and/or engineering problems by relying exclusively on their conventional methodologies, problem modelling and analysis methods, and by following approaches driven by their specific practice. As their daily practice and the current literature show, this period is over. The time available for development and engineering is becoming even shorter due to an increasing market pressure, while products are supposed to be even more competitive and able to penetrate into new application domains. Concurrently, the design and engineering activities are becoming more challenging due to the growing complexity, connectedness, multi-disciplinary nature of products and services, as well as due to the

intense interactions with humans and the environment. Many new requirements should be fulfilled for the reason that products and services are expected to be sufficiently innovative, user-centred, high-technology enabled, knowledge-intensive, ecologically and socially sustainable, and materials- and energy-concerned.

To be able to fulfil these requirements designers and engineers need to have new and extensive insights, guiding principles, structured workflows, and experiential knowledge. Altogether these lead to the need of more knowledge-intensive processes, products and services. One way of increasing knowledge-intensiveness is involving research. This can happen explicitly or implicitly (i.e., using already existing methodologies, technologies, practices, and data) in product development processes. This, however, more often than not, raises many organisational, procedural, professional and personal issues and challenges for designers and engineers. An obvious challenge is having the proper know-how on how to include and benefit from research activities in design and engineering processes. This often goes together with other issues, such as awareness and understanding of research methods, and doing research with sufficient rigor and efficiency under time and capacity constraints. To cope with these challenges, many companies outsource research activities as part of their supplier-based working strategies. This is typical in the case of companies, which are in the lack of dedicated research facilities, personnel and expertise, but which want to possess novel research knowledge and technologies. However, the above knowledge acquisition strategy can usually be not applied in the case of small and medium-sized enterprises due to various resource and procedural limitations. Their designers and engineers are supposed to contribute not only to the execution of product development processes, but also to the enhancement of intelligence of processes and products by new knowledge, otherwise the company cannot build up or maintain its competitiveness.

Towards the above end, designers and engineers of small and medium-sized enterprises are to be aware of the importance of new knowledge. They are also to learn and master how product development and engineering processes can be enhanced by involving research. The recognition of this need has been transferred into orientating questions for this special issue: What can academic research tell for industrial practitioners about the inclusion of research activities in product design and development processes? What research management approaches are currently used in product development and engineering? How do industrial practitioners extend their knowledge platform, make more reliable and robust decisions, and enhance the outcome of their creative, collaborative and/or testing actions run-time? In addition, our interest also extended to:

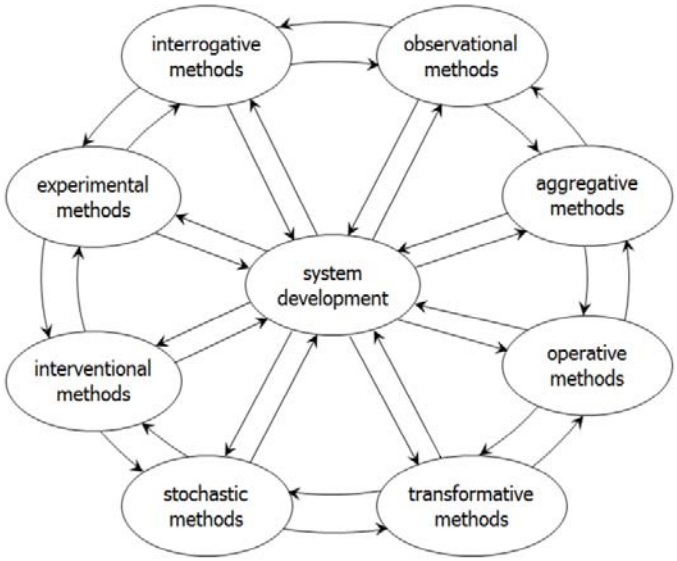
1 the kinds of the research methods used

2 operationalisation of research methods in the context of product development and engineering

3 integration of research methods with the core design and engineering activities.

Finally, we also intended to learn how the knowledge explored by systematic research is combined with intuitive (tacit) design and engineering knowledge (Holifield et al., 2008)?

Figure 1 Multi-method approach of technical system development



The research approaches and methods that designers and engineers can choose from are widely discussed in the literature. Typically, standard and domain/task specific research methods are distinguished. The kinds of standard methods are shown in Figure 1. They can equally well support knowledge exploration, theory development, justification of theories, and validation of research results/findings. We included many examples of domain independent standard research methods in Table 1. It is often questioned in the literature if design and/or engineering activities can also be used as research methods, or if product development (i.e., synthesis of systems) can be considered as a valid research methodology? This is a relevant question, because many industrial practitioners and even academic researchers believe so (Zimmerman et al., 2010). For instance, Nunamaker et al. (1991) placed system development in this position in the context of information systems research. Taking this position is underpinned by the reasoning of Blake (1978) according to which development is the systematic use of scientific knowledge directed toward the production of useful materials, devices, systems or methods, including design and development of prototypes and processes.

Table 1 A concise overview of standard research methods

Kinds of methods	*Standard research methods*			
Aggregative	Literature study	Documents analysis	Query-based web search	Algorithmic information mining
Observational	Naturalistic observation	Laboratory observation	Protocol study	System (self-) monitoring
Interrogative	Questionnaire survey	In depth interview	Self-reporting	Focus group session
Experimental	True experiment	Quasi-experiment	Instrumented measurement	Explorative case analysis

Table 1 A concise overview of standard research methods (continued)

Kinds of methods	*Standard research methods*			
Interventional	Physical specimen testing	Clinical testing	Planned user trials	Active diagnosis
Stochastic	Frequentist statistical analysis	Bayesian statistical analysis	Random statistical analysis	Evidence-based reasoning
Transformative	Problem formulating studies	Abductive model synthesis	Proofing of tangible concepts	Evolving system development
Operative	Model-based investigation	Simulation-based study	Action research	Practice-based research

Nevertheless, other authors argued that a more articulated view is necessary. Some argued that the genuine (formal) research methods may be complemented by methods of systems development towards broadening and enrichment of knowledge, but we must not forget about the issues of theory justification and knowledge validation (Horváth, 2008). It has also been proposed to consider the various manifestations of the developed products a tangible hypothesis (Van den Hoven et al., 2007), and to use them as evolving research means in multiple cycles of research (Horváth, 2013). Using process, artefact and methods prototypes may allow researchers to get to new insights or enhancement knowledge that cannot be accessed otherwise. At the same time, the more contextualised the research activities are, the more difficult to decontextualise and generalise the obtained knowledge.

The papers included in this special issue are regarded as representative examples of the efforts and achievements in the field of applying research methods in product development and engineering processes. The papers selected for publication cover a wide range of product development challenges and issues, as well as application fields. We think that these application cases and the addressed problems offer a multitude of opportunities for involving various standard and specific methods in creative processes. The selection of the papers indicates that the issue of including research activities and methods in product development processes is somewhat trans-disciplinary (Van der Vegte and Vroom, 2013). The papers included in this special issue were originally presented at the Ninth International Symposium on Tools and Methods of Competitive Engineering (TMCE 2012), that was held in Karlsruhe, Germany, from 7th until 11th May, 2012. The papers went through a multi-phase review process, including the original peer review and revision for TMCE 2012, followed by the study, extension and enhancement proposals of the guest editors, and lastly, reviewing and revision for publication in the *Journal of Design Research*. Altogether five full length research papers and an interesting extended technical note are released for further public debate in this special issue.

The first research paper, entitled ‘Analysing the shift of product management strategies concerning ETO products’, by Aicha Amrani-Zouggar and Marc Zolghadri, aggregates knowledge to facilitate the development of a decision support tool. The paper presents the results of the research work completed in the ESTIMATE research project, which was funded by the European Commission. The authors’ intention has been to reduce the lead-time of engineered-to-order (ETO) products though the related product management is a complex process requiring many interactions with suppliers and

sub-contractors. They observed that some components are managed by the make-to-stock (MTS) and others by the make-to-order (MTO) or assemble-to-order (ATO) product management strategies in the case of ETO products. They also observed that the selection of the most relevant part management strategy has an impact on the overall lead-time of ETO products. The authors analysed this product management strategy on two levels, namely, on strategic and tactical levels. They found that selection of a proper product management cannot solely be based on the ongoing product development project. Formal and tacit knowledge from parallel running projects, previously gained experiences, and product portfolio aspects have to be considered as well. The main research methodology the authors applied was critical analysis. Relying on this, they identified the main factors that caused and influenced the shift of product management strategies from ATO to MTS and MTO in the case of the parts of ETO products. Their theory was converted to and formalised in a shifting algorithm, which in turn has been implemented as a computational tool, and made it possible to develop knowledge for a methodology to support shifting product strategies.

The second research paper is contributed by Driss Essabbar, Marc Zolghadri, Maria Zrikem and Abderrahman Ayadi under the title 'Rule-based modelling of dependencies among activities in collaborative partnership'. The main objectives of the authors were to understand the behaviour of companies when they operate in a network of partners and to comprehend their interrelation dependencies. Towards this end, they introduced a generic definition of dependency, as well as the typology of dependencies (links) that may exist between the dependent elements. They analysed and explored the dependencies of activities in a design and development process conducted with multiple partners, and proposed a structured set of rules to formalise these dependency relationships between activities. The authors reasoned from the activity-dependency relations towards dependencies among the partners. Using the inference based on weak and strong rules, more sophisticated dependency relationships were deduced. Owing to this, constraints that are to be shared among the partners can be defined before a product development project commences. The authors applied logical formalism and reasoning to capture dependency relationships and inference rules. The results of this work should be further investigated in complex industrial cases.

Co-authored by Aleš Slak, Jože Tavčar and Jože Duhovnik, the third paper, 'Case study analysis and genetic algorithm adaptation for job process planning and scheduling in batch production', aims at the development of optimum process plans for the production of turned parts. The process plan serves as the basis of determining the sequence of operations across the available machines in order to be able to produce products timely in batch production. This batch production must be adapted to customer's demands and unpredictable events such as additional orders, cancellations, malfunctions, and changes. These raise the need for prioritising and context sensitive scheduling, which the authors address by adapting and using a genetic algorithm (GA). The proposed GA iteratively searches for schedules that fulfil the process constraints. Instead of the usual one-criterion optimisation, the GA simultaneously considers three criteria, namely reducing: time, make span, and costs, at searching for a good enough schedule, closely approximating the optimum. The article presents how the GA-based approach was applied to the problem of producing turned parts, and the results were compared with the results obtained by an existing enterprise resource planning (ERP) system. It is a kind of novelty that GA-based approached addressed the integration of an improved planning and scheduling algorithm into an existing manufacturing system, rather than the calculation

procedure only. The development of the algorithm, and using it as a research means, resulted in new knowledge about scheduling on the basis of using data from an ERP system.

In the paper 'Research and confirmation of an anti-counterfeiting approach for product authentication based on documentation enhancement', the authors, Michael Abramovici and Andreas Krebs, present an approach to avoid unintended purchase or use of counterfeit products. Counterfeits, such as product forgery and plagiarism, represent a problem on a global scale, and they affect many branches of the making industry and trade. Based on a literature analysis and critical thinking, the authors proposed advanced product authentication as a possible solution. The proposed methodology relies on the enhancement of product documentation by including product-related data, as well as verification methods for these data. This anti-counterfeiting approach provides reliable information about unique properties of product items via references stored on identification marks that are attached to the products. Customers or users can securely access the enhanced product documentation and authenticate goods by using ubiquitous computing technologies embedded in handhelds or mobile phones with embedded cameras or near field communication readers. If the testing does not raise confidence about the authenticity of a product, then the proposed system offers a list of repair shops, which can be contacted for their expertise. The proposed approach was validated through three case studies with a statistically relevant number of test persons. In these cases, the developed testing guidelines were used. The authors also offer a design method for the enhancement of product documentation. The widely ranging knowledge aggregation, the theory development and the case study-based validation makes this work procedurally and epistemologically reasonably complete.

In the fifth research paper, entitled 'Bulk simulation of physics and interaction aspects of products: formal underpinnings and proof-of-concept implementation', Wilhelm Frederik van der Vegte and Zoltán Rusák provide the theoretical basis of a novel method for integral simulation of the use of products. The proposed method aims at performing simulations much faster than they happen in real-time in non-interactive environments, where algorithms running on a computer act as a surrogate human subject and where stochastic variations in user actions can additionally be taken into account. Based on a unified finite-automata representation for models of physics processes and specifications of information processing, the method supports the design of products and product-service combinations, the workings of which do not heavily depend on spatial manipulations, human dexterity, and continuum physics. Methodologically, the research work started with a literature study. Afterwards, the underpinning theory was deduced based on propositional logic, theory adaptation and theory integration. This was followed by the development, experimental application, and systematic testing of a proof-of-concept implementation. This latter involved a quantitative analysis of data obtained from multiple simulation runs in a practical case. In the realisation of the proof of concept tool, general-purpose commercial software, such as Matlab Simulink with Stateflow, was used. The faster-than-real-time simulation capabilities make it possible for designers to benefit from what-if studies using bulk simulations.

Finally, the extended technical note contributed by Jérémy Lefèvre, Sébastien Charles, Magali Bosch-Mauchand, Benoît Eynard and Éric Padiolleau addresses the issue of 'Multidisciplinary modelling and simulation for mechatronic design'. This is a hot topic because integration of heterogeneous components and achieving synergy on system

level requires a comprehensive use of multidisciplinary system engineering models and methods. The paper proposes solutions for increasing the interoperability of models and for facilitating a multidisciplinary simulation of mechatronics designs. To increase the interoperability of models, authors developed the concept of a 'global model', which is in fact a composition of various sub-models expressing the technical views of a simulation expert. SysML and Modelica were coupled to support multidisciplinary modelling of complex behaviours of systems. In addition, mesh-based parallel code coupling interface was applied to interface with CAE application software. STEP AP 2xx application protocols were used for neutral data exchanges and PLCS for managing the data in a global PLM approach. The results of the research were used in a PLM platform development in the EXPAMTION for a concrete industrial use case. The authors experience is that the proposed global-model-based approach can increase the interoperability applications and improve the modelling and simulation activities in the case of mechatronic systems. It was also found that it remains difficult to ensure optimal communication among application software from different developers due to weakness of the translation mechanisms of mathematical models and parameters, especially in terms of dimensional accuracy.

The papers included in this special issue raise new issues, but also present new opportunities for research-enabled increase of knowledge intensiveness and innovativeness of product development processes. Our sincere hope is that, through this composition of papers, we have managed to cast light on some challenges and approaches of enhancing practical product development activities through the involvement of operative research and provide some convincing application examples. We are extremely grateful to all authors for their contribution to this special issue, for their nice collaboration in the review and revision processes, and for their commitment and efforts to achieve the best possible quality. Nonetheless, we are indebted to our reviewers who helped us to increase the scientific/professional value and quality of the papers through their constructive comments and objective recommendations.

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