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Agile Management in Hardware Related Design Projects

Christoph Maurer
Professor
University of Applied Sciences Munich
Germany

Lars Brehm
Professor
University of Applied Sciences Munich
Germany

Anne Bergner
Professor
Coburg University of Applied Sciences and Arts
University of Applied Sciences Coburg
Germany

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Athens Institute for Education and Research
8 Valaoritou Street, Kolonaki, 10671 Athens, Greece
Tel: + 30 210 3634210 Fax: + 30 210 3634209 Email: info@atiner.gr URL: www.atiner.gr
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Christoph Maurer
Lars Brehm
Anne Bergner

Abstract

During the past decade, agile project management became a common method in software development. Deliverables are submitted in stages in short delivery cycles. The detailed definition of the final product is created while developing the product. Interdisciplinary self-organized teams are working on the project within a clearly defined schedule. Thus, the product meets the customer´s needs better and can be brought to the market faster. A survey in German mechanical industries performed by the authors is introduced, which demonstrates the broad interest of practitioners in this field. This paper investigates the chances to apply agile project management methods tohardware related design projects. Usually hardware design cannot be handled as flexibly as software design, thus commonly a detailed specification list is the first step required in hardware development. But why not let the product definition grow while the project is in progress? Why not submit discrete modules in short cycles instead of waiting until the entire product is specified? The authors distinguish between parts of agile project management methods that can be directly leveraged and parts that offer opportunities for adaption. Also comparisons are made between other approaches, such as Design Thinking. The types of projects that may be suited for agile management are characterized. In addition, aspects of corporate culture and demands to be met by design managers are brought into focus.

Keywords: Agile Management, Engineering Design Projects, Industrial Design Projects, Scrum.

Introduction and Research Approach

The engineering design domain provides well-established processes including detailed procedures and norms for designing a new product and conducting a new product development project. These processes follow in general a linear sequence of in-depth described steps.

In the industrial design domain, a vast amount of descriptions on the design process (e.g. double diamond or design thinking method) exists, but these models are not so detailed and do not provide such a prescriptive character. The aim is more to facilitate the cognitive process in the design flow and to communicate the designer's approach to problem solving. There are no standards or protocols thatrequire compliance.

Both design approaches and the cooperation of engineers and designers offer potential for improvement.

During the past decade, agile project management became a common method in software development and it has shown significant improvements in successful delivery of valuable results to the customer. Scrum is the favorite agile project management method (Budde, 2015). It has the following features: Deliverables are submitted in stages in short delivery iterations. The detailed definition of the final product is createdthrough development. Small interdisciplinary self-organized teams are working on the project within a clearly defined schedule, and it utilizes certain predefined times for reflection. Thus, the product meets the customer´s needs better and can be brought to the market faster (Sutherland and Schwaber, 2017).

This paper investigates the chances to apply agile project management methods on hardware related design projects.

For this purpose, the authors analyze the current processes and procedures resp. norms in engineering design as well as in industrial design. Then details of scrum as the favorite agile project management method are described. Based on that, the parts of agile project management methods are presented which can be directly leveraged, as well as the parts thatoffer opportunities for adaptation. Additionally, the authors discuss potential solutions, required adaptations and aspects of corporate culture. Demands to be met by design managers are also brought into focus.

As a conceptual paper, this article combines the common views of several disciplines on the topic of product design projects and analysis of how agile project management methods can improve product design project and which adaptations are required. This judgment is based on the substantial background of the authors in their fields.

Brief Literature Summary

In the IT sector, agile project management methods are widely used to increase project success rates, reduce time-to-market, develop innovative solutions in higher quality and attract talents (Rigby et al., 2016). 'The IT world has shifted from slow "waterfall" methodologies to agile techniques such as “scrums”’ (Willmott, 2015). Agile Management is starting to become more and more recognized outside IT – for example, Rigby at al. discuss in the Harvard Business Review how to embrace agility. From the agile project management methods, Scrum is by far the most used one, especiallyin traditional software companies – see for example the analysis of Begel and Nagappan at Microsoft (Begel and Nagappan, 2007). Scrum was developed by Sutherland and Schwaber in the mid-90s. They both still publish together “The Scrum Guide - The Definitive Guide to Scrum: The Rules of the Game” containing principles, roles, process and artifacts of Scrum (Sutherland and Schwaber, 2017).

There are some initial approaches to apply agile project management (especially Scrum) to hardware related projects (Wagner, 2014; Huang et al., 2012). However, theyeither they lack empirical validation or have an extremely narrow application focus. Additional empirical research of the applications of agile project management to industries other than IT (Conforto et al., 2014) focus on specific agile management practices, but not specific enough to hardware related projects.

With the trends towards Internet of Things (IoT), smart, connected products (Porter et al., 2015) and more artificial intelligence in physical devices, these hardware related projects will become more and more important.

State of the Art in Hardware Engineering Design Processes

Products developed in the field of mechanical engineering or mechatronics to a considerable amount consist of hardware. Hardware in this context means physical parts manufactured of metal, plastic or other materials, for example levers, bearings, shafts, gears, springs, housings. Hardware parts can be typified by the necessity of physical, thermal or chemical treatment of materials that finally provide the desired shape and function. Those hardware parts are assembled and combined with sensors, actuators, electronics and software to form a functional unit or a machine.

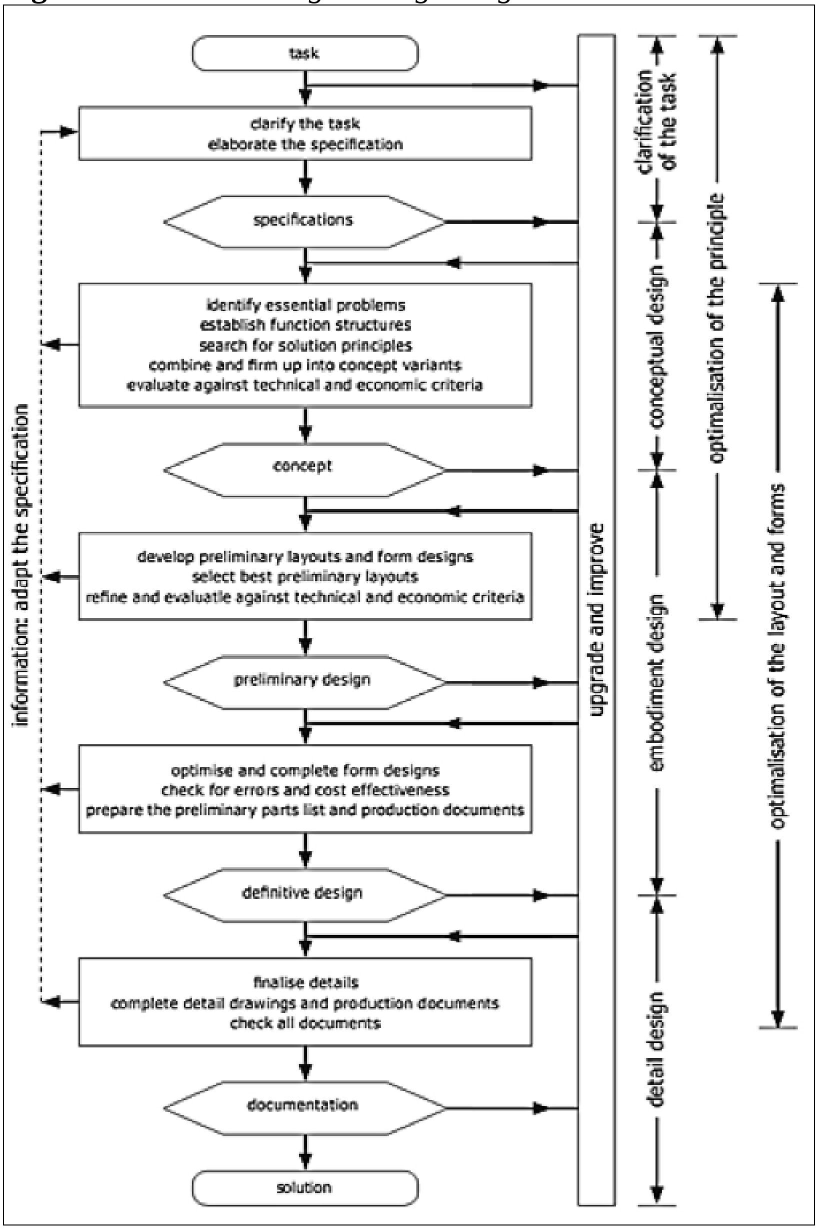
Before manufacturing and assembly, hardware must be designed and calculated not only to ensure proper function but also to guarantee that the parts withstand all internal and external forces and loads during their intended use. Furthermore, for economic reasons, design and calculation should minimize the costsof material and manufacturing.

After design and calculation, usually a prototype is built and tested before starting production and bringing the machine to the customers.

The process depicted logically implies the necessity of fully describing all properties of the machine in detail before starting the design process and before producing and bringing the product to market. All common process descriptions for hardware development processes postulate a complete and detailed specification list of the entire product at the very beginning of the design process. During the design process, all components are defined and designed in detail before they canbecome real parts in production. Onlythen can the product be assembled, tested, and shipped to the customer.

The whole product design and development process is strictly linear and serial comprising some iteration steps. Figure 1 illustrates an exemplary description of the hardware design process (VDI, 1993; Pahl et al., 2006). Thus, the time from the identification of user´s needs to the solution is very long.

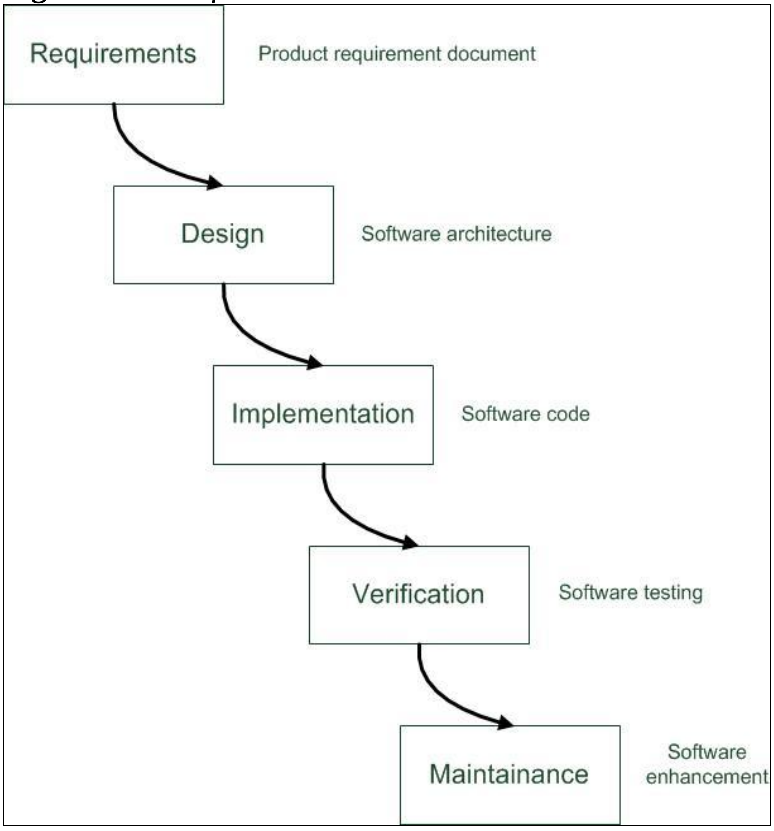
Figure 1. *Hardware Engineering Design Process*



Source: VDI, 1993; Pahl et al., 2006.

Production cannot begin before the complete design process is finalized. Then the shippable product can be manufactured. Thus, revenue and profit contribution are generated at the very end of a long value chain. Furthermore, once the process begins, it is impossible to allow for changing demands from customers. During the past decades, system engineering was introduced, including new models such as the V-model (VDI, 2004) or the waterfall model shown in Figure 2. Nevertheless, all existing process models follow a linear structure and require a detailed description of the product at the very beginning of the development process. This still represents state of the art industry levels for developing hardware related products.

Figure 2. *Waterfall-Model*



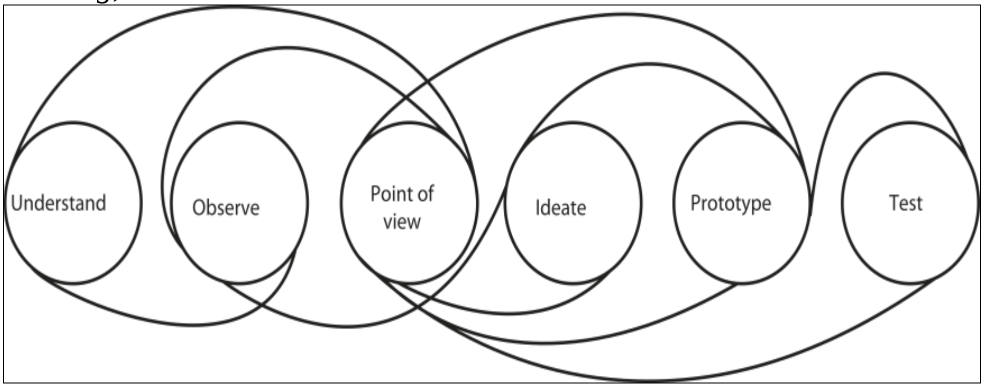
State of the Art in Industrial Design Processes

Unlike that observed in the engineering design context, in industrial or product design there is not a standard model or norm guiding the design process. To describe the distinctive activities that designers routinely undertake in the design process, the term “Design Thinking” has disseminated widely, even beyond the “borders” of design disciplines (Martin, 2009). Design thinking is a methodology to generate innovative ideas involving the idiosyncratic strategies, tools, priorities and objectives of designers (Brown, 2009; Nussbaum, 2008). Regardless of the success of the methodology, there is no universally agreed upon definition of “Design Thinking” (Lindberg, 2013) – including the question of whether design thinking can be regarded as a methodology or rather as a more general approach to problem solving or personal mindset. This - and the misinterpretations and inflated expectations communicated in popular literature - has led to confusion about the nature and merit of design thinking (Dorst, 2011).

Nevertheless, some distinct core principles of design thinking can be identified, such as the centrality of the user and empathy to the human condition (human-centered design), the generation of fast prototypes, working together as a multi-disciplinary team, and a consecutive iteration in which the team will move to gain a deeper understanding of the problem which has to be to be solved.

In those models of design thinking thatembrace a more formalized process (e.g. design thinking model as proposed by HPI school of design thinking, Potsdam) these steps are defined as “understand”, “observe”, “point of view”, “Ideate”, “prototype” and “test” (Figure 3).

Figure 3. *Design Thinking Process as proposed by HPI School of Design Thinking, Potsdam*



Source: Own illustration based on HPI school of Design Thinking.

In direct comparison, some similarities betweencore principles of design thinking and agile management can be found. While design thinking is a much less described process, the aspects of iteration, customer orientation, group creativity and prototyping are of vital importance in both approaches.

Agile Management in Software Development Projects

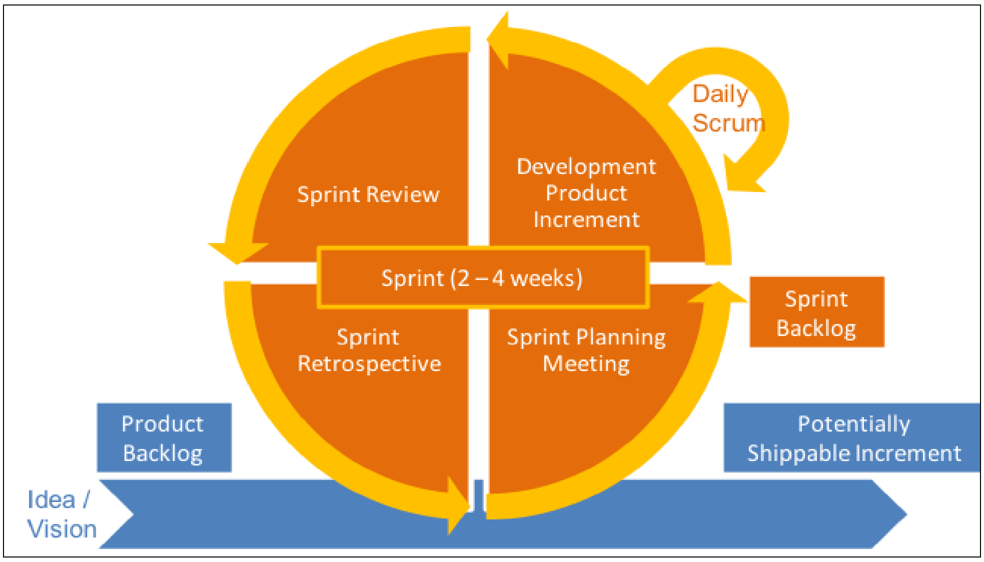
Despite the fact that the waterfall-model and V-model are still commonly used in software development projects, there is a clear trend towards introducing agile product development in the software industries. Agile management in this context is very often the scrum approach (Komus, 2014). Scrum follows, like other agile management approaches, the principles of the agile manifesto. The agile manifesto originated in 2001 witha group agile-oriented people, including Jeff Sutherland and Ken Schwaber - the creators of scrum (“Manifesto for Agile Software Development”, 2001). It contains four principles, whichare:

- Individuals and interactions over processes and tools
- Working software (now solutions) over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

Scrum is based on lean principles and the description of scrum itself is lean as well. It is fully presented in the so-called Scrum Guide of only 16 pages (Sutherland and Schwaber, 2017). Scrum aims for developing and sustaining complex products and contains only threedifferent roles (product owner, development team and scrum master), fivescrum events (the sprint and 4 special types of meetings) and threescrum artifacts (product backlog, sprint backlog and increment).

The main working cycle in scrum is a sprint with a length of 2-4 weeks resulting in a working increment of the product. Within a sprint the development team, which is cross-functional in nature, develops completely the function they agreed on at the beginning of the sprint in the planning meeting. The product owner ensures the translation of the stakeholders' vision into a product backlog of requirements (often in the format of user stories) sorted by the value to the stakeholders. In the sprint planning meeting, the development team decides what from the product backlog can be done within the next sprint and how it will get done. This defines the sprint backlog. During the sprint, the "daily scrums" (15-minute time-boxed meeting) ensure that the development team synchronizes their activities and plan the next day. At the end of a sprint, the developed working increment is inspected and "handed over" to the stakeholder during the review meeting. The last event in a sprint is the sprint retrospective, which helps to identify opportunities for improvement. Figure 4 gives a graphical overview about scrum.

Figure 4. *The Scrum Process showing the Artefacts, the Sprint and the Daily Scrum*



Source: Timinger 2015, p. 70.

Overall, scrum has the following characteristics: itvalues the principles of transparency, frequent inspections, and fast adaptation. Scrum is based on a self-organizing team of professionals with high restrictions on interruptions from outside. It ensures the empowerment of the scrum team, promotes cross-functional skill sets within the team and limits the scrum team size to a maximum of 11 people (ideally co-located) to reduce distractions and foster group creativity. All meetings and the sprint itself are time-boxed and thus have a maximum duration. Compared to “classical” waterfall project management, in scrum project management, time and costs are fixed, but scope is flexible. Only the sprint backlog - as the goal of current sprint - is fixed. The remaining fixed horizon is always during the whole project maximum of 4 weeks. The product backlog can be changed by the product ownerat anytime. So, not all requirements have to be known and defined upfront; changes to the requirements are welcomed and seen as better knowledge about which requirements provide the highest business value in the current context. There is a high transparency through visualization e.g. by having the product backlog sorted by business value and the display of the sprint progress on a (physical) scrum board.

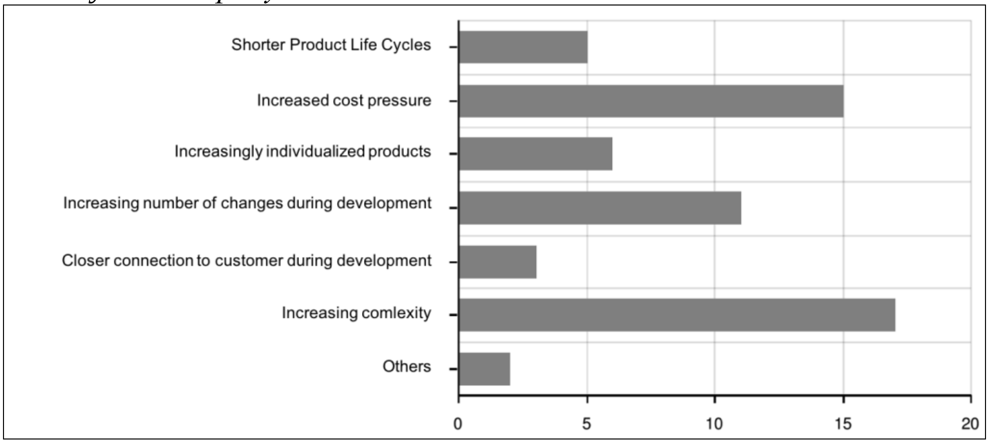
Survey in German Industries

A survey in German mechanical industries performed by the authors demonstrates the broad interest of practitioners in this field.

The aim of the study was to identify current trends and challenges in that industry and analyze the knowledge about and application of agile management at the participating companies. Our online questionnaire was provided to approximately 100 professionals, mainly heads of research & development, product engineers, innovation managers and project managers, in German mechanical industries. Twenty-sevenprofessionals responded tothe survey, which was performed between November 2016 and January 2017.

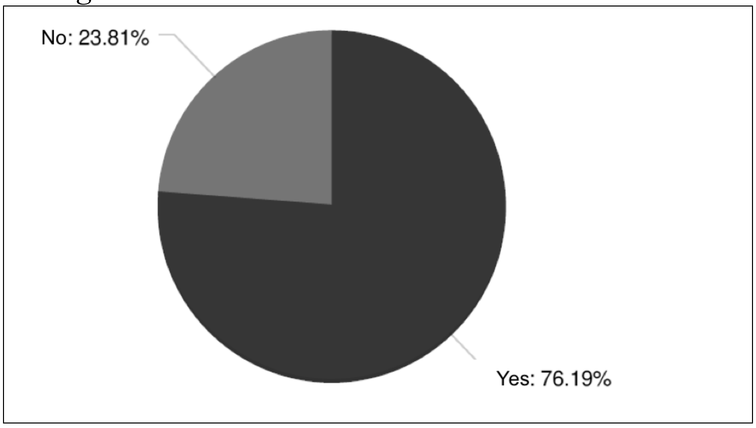
The first results are about product development in the participant’s company. The question was “Which actual changes do you observe within your company?” The participants see here a number of interesting items as shown in Figure 5.

Figure 5. *Answers on the Question "Which Actual Changes do you Observe within your Company?"*



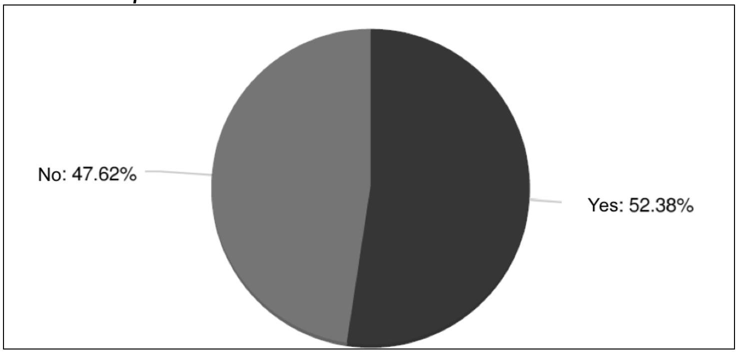
The main challenges are increased complexity, as well as increased cost pressure. Furthermore, the increased number of changes during development is a relevant change in the companies. As argued in this paper, agile management could be a solution to tackle these challenges. Additionally, we were interested to see how many participants are familiar with the term "agile management". Nearly three quarters are familiar with that term (see Figure 6).

Figure 6. *Answers on the Question "Are you Familiar with the Term Agile Management?"*



We asked also, if the participants utilize agile management or parts of it already in their companies. Over half of the respondents answered with "yes" (see Figure 7).

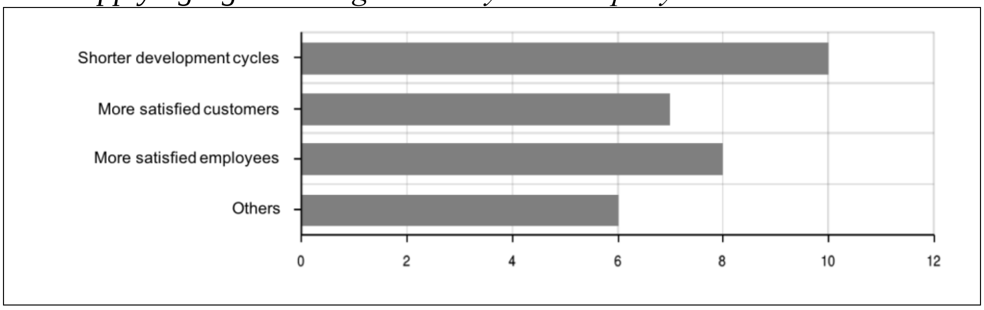
Figure 7. *Answers on the Question "Do you Already Apply Agile Management or Parts of it?"*



Both numbers in Figure 6 and Figure 7 appear to be quite high. Yet,due to the survey topic, we assume that mainly participants with at least a basic understanding and interest took part in the survey.

Additionally, we asked what the expected benefits of agile management might be (question: "which main advantage do you expect when applying agile management in your company?"). Time-to-market was the most often named benefit, followed byhigher satisfaction of customers and employees. Figure 8 gives details on these replies.

Figure 8. *Answers on the Question "Which Main Advantage do you Expect when Applying Agile Management in your Company?"*



Overall there is some knowledge about and utilization of agile management in German mechanical industries, and there are clear expectations. However, the in-detail application is still unclear and needs to be carved out.

Potential Advantages of Agile Management in Hardware Development

Looking upon the big advantages scrum offers in software projects today, it is an alluring prospect to transfer scrum and apply it tohardware related design projects. Assuming that a seamless transfer ispossible, hardware development projects could be faster, cheaper, more flexible, closer to customer´s needs and economically more efficient.

Obviously, however, the transfer is not possible in a 1:1 ratio, mainly because software consists of only virtual existing lines of code, while hardware consists of physically existing parts and material. Software code can be created faster without involving any manufacturing facilities and using only computers. Software can be changed and adapted rapidly with no physical material involved in the changes. Therefore, if the potential that scrum offers is supposed to be raised for hardware, certain conditions have to be defined and rules have to be developed.

How Features of Scrum fit into Design Engineering and Industrial Design

Based on our experience in more than 100 projects, we distinguish features of scrum that easily would fit into the design engineering discipline and such features that would fit with difficulties. The same was done for the industrial designer discipline. An overview is given in Table 1.

Table 1. *How Scrum Features Fit into Design Disciplines*

Scrum Feature	Engineering Design	Industrial Design
Definition of product is developed while developing the product	difficult fit	easy fit
Part-deliverables are finished and submitted in short delivery interactions	easy fit	difficult fit
Small interdisciplinary self-organized team	easy fit	easy fit
Reflection after handover of each deliverable	difficult fit	easy fit
Team is well protected from interfering with management and internal or external disruptions	easy fit	easy fit

With good reason, not all scrum features are accepted by industrial designers or design engineers. Furthermore, the fits are not superimposable. Usually both disciplines will have to work closely together in hardware related development projects. In order to accomplish acceptance, it will be necessary to adapt agile management methods to make them fit for industrial designers, as well as for design engineers.

Proposed Adaptations of Scrum for Hardware Development

Being familiar with the application of scrum, as well as traditional engineering design and industrial design methods, the authors recommend adaptations of scrum in order to gain the most of the advantages offered. Two main aspects are observable: Every single project has to be adapted, and, in addition, it must be ensured that the organization of the company is matched with the requirements of scrum.

Project Aspects

- The project must be handled by a self-responsible, cross-functional scrum team. The team must cover all aspects to solve all problems coming up during the project. Depending on the project, it may consist of industrial designers, engineers, IT, production engineers, product managers and marketing managers.
- The project structure must be tailored to split the product into increments that can be treated separately by the team. Clearly defined interfaces between increments are crucial.
- In order to develop pieces of shippable or at least presentable hardware, new technologies like 3D printing might be applied. The resulting increments can be given to customers in a very early stage and their feedback helps to improve the product.
- Sprints might take longer than the strictly postulated maximum of 4 weeks by scrum. Each cycle from idea to increment of product may take longer since creating hardware takes time.
- Only rarely direct business revenues can be created by selling the increments directly after they are finished.
- When generating hardware mostly production managers and purchasing managers will be involved in addition to industrial designers and design engineers.
- The product backlog must be derived from the product vision. The problem must be defined, the design briefing should have taken place and the general solution space for the problem should be fixed before the team starts it´s work.
- The stakeholders for the project must be defined. This could be internal people (product managers, marketing managers, etc.) as well as external people (customers, dealers, etc.)

Organizational Aspects

- Research on collaborative creativity has shown that a high level of diversity amongst team members, mutual trust among the participants and the sense of ownership in the collective vision promote the creative output of teams (e.g. Sawyer, 2008). This seems to be a highly important aspect of scrum.
- The same applies to clear principles of interaction, a high degree of independence and limitation of executive control, which are also integral principles of scrum. Management must fully rely on the team and trust, instead of control, is required. Theteam must be protected by the management from any internal or external interference disturbing their work. Many hardware-related engineering companies do not trust self-organized and fully self-responsible teams. They will have to readjust their corporate culture.
- Phases of reflection thatentail building new understandings also play an important role in the design process (Schön, 1984) as well as in scrum. This should be introduced when applying agile management methods.

- All of these factors often are not recognized as vital and accordingly not prioritized according to their actual importance. This is a mistake. In scrum the rigorous, almost ritual way to ensure compliance with these guiding principles is a key success factor thatalso should be applied.

Applying Agile Management on Hardware Related Projects - Recommendation for Rules

In order to adapt scrum for hardware related projects the authors propose the following conditions and rules:

- Make sure that the corporate culture of your organization is prepared for agile management methods. Management and stakeholders have to trust the product owner, scrum master and the team (both in terms of scrum) and their 100% self-organization. This clearly is not a process-related issue but a cultural issue that must not be underestimated.
- Involve your customers in your product development. This also is a cultural concern since hardware developing organizations still tend to open the curtain not before the product is totally finished. Moreover, customers must be prepared to be involved sequentially.
- Create a structure for the project thatmakes it fitted to Scrum by defining increments of the product that can be treated separately by the team. The nature of these increments might be very different to those delivered in software development and might vary extensively depending on the nature of the project or task. As for industrial design, it seems inapplicable to design one specific component without connection to an overall design concept.
- The time of a sprint should not be extended too long over the 4 weeks recommend for Scrum. Adjust the estimated workload for an increment to fit into 4-8 weeks. It is not about creating perfect hardware. It is about some “physical sketches, mockups or rapid prototypes” that can be presented to the customer.
- Reduce the claim “potentially shippable increment of product” used in scrum to “presentable increment of product”. The increment generated in a sprint should be presented to the user and tested. It could be a finalized component fully operable. On the other hand,it also could be a simple model demonstrating handling, design, basic functions or similar. The only prerequisite is that something has to be demonstrated to the user.

Summary and Outlook

Agile Management cannot be leveraged 1:1 from software projects to hardware related projects. Single elements of agile management can be applied when considering certain boundary conditions and following some rules. Thus, hardware development can be made faster, more efficient and the quality of the outcome can be improved. Aspects of the corporate culture must not be underestimated. Full trust of the management in the self-responsible and self-organized team is an essential prerequisite when using elements of agile management methods in hardware development projects. For the next step, the authors intend to apply their findings toreal projects starting with students working on industrial projects at university.

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