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AGILE METHODS FOR DESIGN TO CUSTOMER

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ABSTRACT
Not only products but also product development get more and more complex. International teams at different locations spread over the globe have to elaborate adequate solutions in shorter project cycles. Market conditions are rapidly changing not only caused by increasing demands on individuality but also due to political, economic and ecological influences. In order to remain competitive, customer satisfaction is the key. A major hindrance in this context is the limited ability of customers to express or even comprehensively identify their own requirements. But also manufacturers often have a lack of knowledge concerning their customers or relevant target groups. The approach delineated in this contribution introduces a concept of adopting agile methods of the software community to engineering, which allows detecting aberrations from demands and requirements early in the development process. The aim is to iteratively build (virtual) prototypes that consider only the main and obvious requirements in the first step. After each iteration an evaluation discloses whether the realization has met the expectations or not and additional requirements can be taken into account for the next step. This minimizes the overall risk of developing unsatisfactory products.

Keywords: Design to Customer, Agile methods, Iterative prototyping, Agile Product Development

1 INTRODUCTION

As a result of globalisation, product development has become highly dynamic and complex. Former suppliers' markets turn to customers' markets entailing the creation of individualised products and thus aggravate the need of implementing specific demands and requirements. Conventional product development methods often premise predictive in depth planning, which has to take place prior to the project launch. This can be a strategic disadvantage in terms of the increasing competition, as a detailed and comprehensive determination of requirements and the actual demands of the client are very time-consuming. In addition, the danger of not exactly anticipating the customer's conception is immanent up to the end of the development process, when the first prototype can be evaluated by the customer.

2 RELATED APPROACHES

2.1 Agile Methods

Agile concepts have been comprehensively developed and investigated by the software community since the middle of the 90s [1] as an alternative to traditional documentation-driven, heavyweight and bureaucratic software development processes [2]. Those processes turned out to diverge in many cases with the way that development teams perform their work. Furthermore, traditional processes impede the detection of changed customer's requirement and aggravate appropriate adaptation measures. As predictive processes are characterised by the successive specification of intermediate results based on results of prior work steps (Figure 1, left), the idea behind agile processes is to complement a solution with additional aspects including all intermediate results in a each step (Figure 1, right).
Agile concepts were initially called "lightweight". Since, 2001, the term "agile" initially established by the Agile Manifesto [2] has been commonly in use. The Agile Manifesto provides a philosophical foundation for effective agile development. It is widely regarded as the canonical definition of agile development, and accompanying agile principles.

Currently, agile approaches are commonly applied within the software community. Agile software development processes are in use at 14% of North American and European enterprises. Another 19% of enterprises are either interested in adopting agile processes or already planning to do so [3].

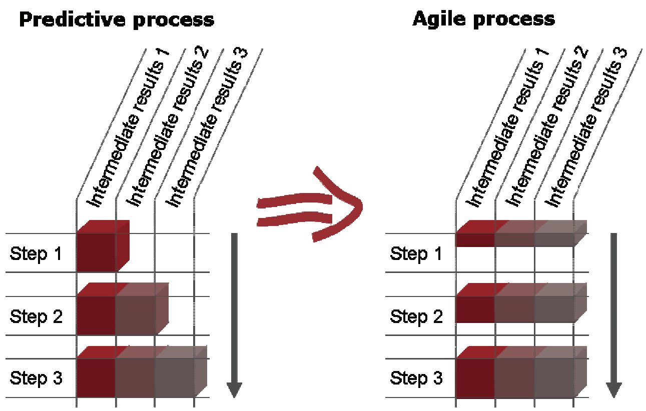

Figure 1. Structural comparison of predictive and agile processes

2.2 Design for X

The decision whether a solution fulfils the given requirements and serves the demands is easy to make in comparison to the technical development and elaboration of the product itself. Usually, the participation of experts, highly skilled engineers and designers is required to ensure an adequate realization. Complex interactions between multiple physical effects within the product have to be managed. Moreover, a suitable and compliant combination and form of each effect carrier has to be implemented. Therefore, there is a complex coherency between the demands on the one hand and the potentially considered solutions (solution space) on the other hand which aggravates the process of solution finding i.e. the elaboration of the design.

In order to cope with this coherency, abstraction generally allows simplifying the actual situation as well as the documentation and reuse of non-context-specific knowledge. Concerning engineering design, the addressed problem is to develop a solution according to the actual demand, which goes further than what has been detailed as part of a requirements list. The demand, specific to a characteristic objective, can be abstracted by extrapolating the targets and subsumption within a generic topic, a so called target characteristic (Figure 2).

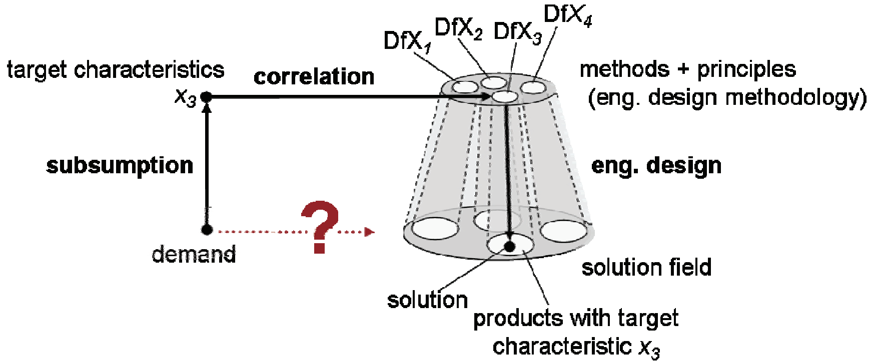

Figure 2. Design for X to develop products with a specific target characteristic

The attribution of a target characteristic to one of the variants of „Design for X/Design to X“ enables a transformation onto the field of engineering design methods (Figure 2). The term „Design for X“ (DfX) describes the anticipation and the early stage consideration of demands within the design, which result out of different phases of a product's lifecycle [4]. It is commonly employed as a generic placeholder for individual approaches such as Design for Assembly, Design for Manufacture, Design for Disassembly and Recycleability, Design for Environment, Design for Lifecycle, Design for Quality, Design for Maintainability or Design for Reliability [5].

Thus Design for X can be construed as a purposeful restriction of the engineering design methodology to subsets of methods, which lead to products consistent with a specific target characteristic. The actual design is reduced to concretion of a target characteristic x_i using methods of Design for X_i (Figure 2).

The abstraction of the demand by means of subsumption of derivated objectives under the umbrella of at least one target characteristic x_i enables a product design according to the methods and principles of Design for X_i. This reduces the solution field to the amount of products with a target characteristic x_i and therefore simplifies the development of an adequate solution.

In addition to the determination of the target characteristics, detailed specification and documentation of the existing demand in the form of requirements is essential for elaborating efficient solutions. Each process, aiming at finding solutions and based on tasks which refer to requirements, e.g. VDI 2221 [6], Pahl/Beitz [7], Koller [8] or even Altschuller [9] can be ascripted to a generic basis structure of a prescriptive-normative engineering design process.

3 AGILE PRODUCT DEVELOPMENT

3.1 Challenges with Design to Customer

With regard to DfX, the term "Design to Customer" defines a concept that leads to customer-satisfying products. Often, there is a gap between the customer's demand, derived requirements and the resulting realization through the manufacturer (Figure 3). Thus the actual product deviates from the original demand.

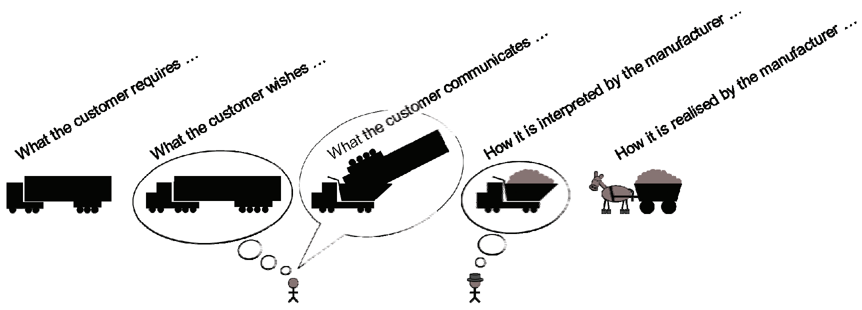

Figure 3. Discrepancy between demand (left) and realization (right)

A discrepancy between the requirements, documented in the requirements list, and the physical product can generally be attributed to company-internal drawbacks. Most often, they take place in the design area or manufacturing. In this case, controlling as well as standardisation and qualification are conventional but effective measures to cope with these problems.
Furthermore, even documented requirements do not broadly reflect the customer's demand. A lack of expert knowledge concerning the problem and incomprehensive information on available or offered products leads to a deficient perception and verbalisation of demand on the customer's side.

Additionally, the manufacturer is not sufficiently familiar with the client's actual issue and is therefore in danger of misinterpreting wishes or desires. Reasons for fact can be found in definitions of target groups, not adequately representing potential customers or client internals which are not accessible and cannot be anticipated. With the existence of a specific target characteristic, a directed restriction of instruments referring to engineering design methods simplifies the design efforts of a product. In this regard, agile process structures, known under the synonym of „Extreme Programming“ [10], „Scrum“ [11] or „Crystal Clear“ [12] in software engineering and also introduced to support the implementation of PDM systems [13] [14] [15]can avoid the discrepancies listed above.
The ongoing development and the increasing spread of digital prototypes open the door widely for an "Agilisation" of the product development process. On the other hand, manufacturing loses importance for evaluating a product and the design process becomes increasingly similar to software development.

3.2 Agile development processes

Conventional approaches are usually of predictive character and can be distinguished as sequential processes where each step is planned based on requirements determined prior to the project launch. Once the development is in progress, changing requirements cause disproportional efforts and costs, the later changes emerge, the larger is the gap between realization, and original demands or project costs increase immensely.
In general, agile approaches aim at minimising the risk by developing solutions in short amounts of time. Agile processes consist of a sequence of iterations, each with the structure of a prescriptive-normative engineering design process (Figure 4) and representing an entire prototype or product. These iterations subdivide the overall process vertically into several segments and each leading to a (digital) prototype. Initially, following the principle of the „low hanging fruits“, only the most essential requirements are taken into account. With an increasing number of iterations, more requirements are gradually considered and detailed.

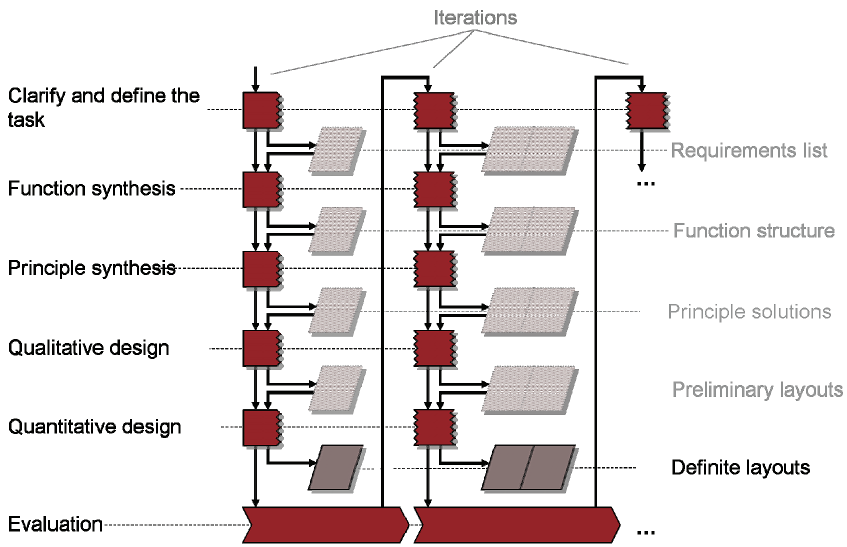

Figure 4. Agile design process vs. the prescriptive-normative process

In order to monitor the progress, an evaluation of the prototype concerning the fulfilment of requirements, takes place between two iterations (Figure 4). With the inclusion of stakeholders, eg. customers or representative substitutes of this target group, an objective evaluation of a complete prototype allows to estimate the match of demand an realization and to take measures (setting up requirements) for the next iteration. In addition, evaluation as part of the predictive methods also takes place within each iteration of agile processes and can be enhanced with principles of Set Based

Design. Unlike conventional predictive processes, agile processes allow a continuous comparison between requirements/demands and the actual design.

3.3 The Agile Continuum

Including principles of Set Based Design into the agile iterations, not only customer focused criteria but also boundary conditions given by the production engineers can be imparted in the design process. By varying the step size of each iteration, a spectrum between agile processes with minimal step size on the one hand and predictive processes with a maximum step size i.e. only a single iteration on the other hand, arises. The risk of agile processes is generally lower, shown through revision costs in case of aberration, compared to predictive processes (Figure 5).

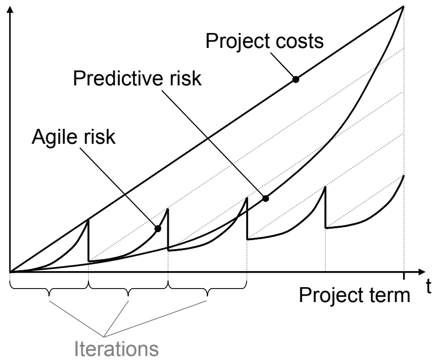

Figure 5. Costs and risks caused by predictive vs. agile design

Predictive processes hold the tendency of detecting aberrations in later phases of the project, as the intermediary results are of high abstraction. Accordingly, the monetary risk increases up to the end of the project. On the contrary, revisions carried out after each iteration of the (incomplete) product as part of the agile process, decrease the overall risk. Figure 6 depicts the relation of costs and risks within the process spectrum. The costs consist of net costs which are directly assignable to project contents as well as planning and coordination (pm-management) costs. While planning costs are more relevant to predictive processes due to more in depth-planning, agile processes cause more coordination efforts to cope with the high process dynamic [14]. As the risk constantly decreases with augmented agility, an ideal process, in terms of costs and risks, generally holds a higher agility than a cost optimal process (Figure 6). An optimal level of agility depends on company-, project- and product specific criteria and can vary in the course of the design project.

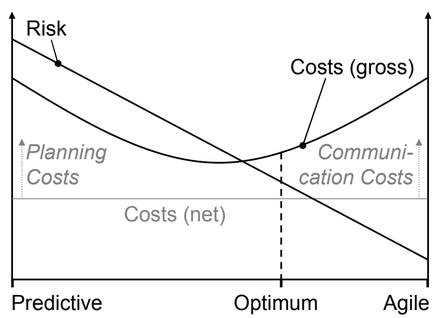

Figure 6. The optimal level of agility concerning costs and risks

In order to determine the optimal level of agility, an approach incorporating heuristic measures is introduced below (Figure 7). Different criteria with influence on the agility level can be considered for evaluation. Generally, the agility decreases with augmenting numbers of directly involved participants. The more people simultaneously work on one product, the more predictive the development will proceed. The degree of conformance is a case specific character which can be expressed by numbers or adjectives and has to be specified with regards to the given application scenario or alternatives.
Each of these alternatives is assigned a gross evaluation which is multiplied by a weighting factor resulting in the net evaluation. In an analogy to conventional evaluation methods the weighting factors must add up to the number one. The agility indicator, which ranges from *-1* to *1*, is the sum of all net evaluations in the last column.

Criteria	Conformance	Gross evaluation	Weighting	Net evaluation
Number of participants	☐ >30 ☐ 21-30 ☒ 10-20 ☐ <10	-1 -0,5 0,5 1	0,4	0,2
Know-How concerning the customer's needs	☐ good ☐ medium ☒ bad	-1 0 1	0,15	-0,15
...				
			Σ=1	Σ

Figure 7. Evaluation sheet to determine an indicator for the optimal level of agility

A strictly predictive process is evinced by an agility indicator of *-1*. An indicator of 1 implies a purely agile process. Figure 8 depicts the dependencies between the agility indicator and the duration of a single prototype iteration. Values can be assigned to the indicator by setting a range of rational timeframes to the ordinate. In the field of product development T_{min} can be set to 1 day (in case of simple products) and T_{max} represents the period of time needed to create the whole product conventionally. Thus, T_{max} usually refers to existing products where project data can be assessed.

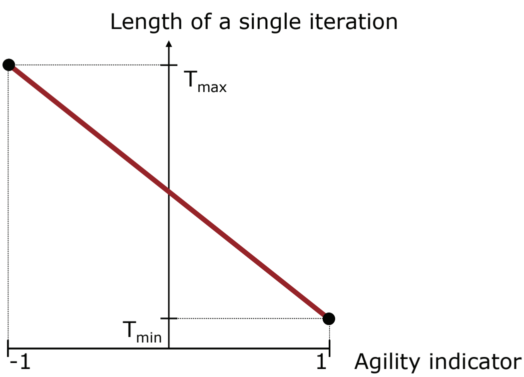

Figure 8. Determining the optimal level of agility based on the agility indicator

The agility indicator determined at the beginning of the project is not a constant value. Changing boundary conditions, e.g. participation of additional project members or integration of new and inexperienced staff, also influence the indicator and hence the agility of the product development. Such discontinuities regarding the agility indicator entail an adaptation of the agility level. Cascading processes provide an appropriate structure to combine sub-processes of differing agility.

3.4 Cascading Processes

An approach to merge elements of agile product development and predictive methods are cascading processes. The basis structure reflects subsequent entities as prevalent in engineering design methods. Iteration is made possible by correction loops pointing back to prior entities. Instead of plain process steps, the mentioned entities are composed of sub-processes, each constituting a pure agile process as delineated above. The transition between two subsequent entities (agile sub-processes) is called a cascade (Figure 9).

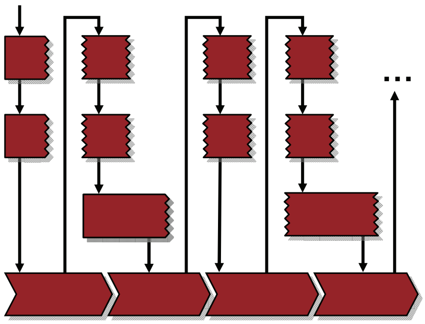

Figure 9. Cascading processes to support changing agility

6 INDUSTRIAL VALIDATION

Validation of the concept has been carried out with different partners in industry. Though the adequate grade of agility for each branch of industry, company and even product differs, the efficiency has increased in all projects where agile methods have been (at least partly) applied.
A partner which develops medical devices has experienced a large number of design changes in late phases of the development process and even after the product has been initially released. Those adjustments and changes have caused immense expenses and corroborated the company to invest in a set of prototypes, each a constitutive of its predecessor, verifying the design prior to the terminal design freeze. Therefore, an initial list of requirements served as basis for the embodiment design phase whereupon principal solutions for the device have been tested virtually as well as physically. If the subsequent evaluation has proven the concept to be feasible, a subcontractor details the design and creates prototypes. The physical parts, demonstrating the entire system and not only single parts, are evaluated and tested by the company, the subcontractor and representatives (users) of the medical profession.

All in all, one concept phase and 4 prototype phases have been realized. As there have been different promising design options, the first 2 iterations took place in parallel leading to a decision on which product concept should prospectively be pursued. In this manner, also principles of set-based design have been imparted and support the agile concept. The last 2 iterations were of sequential character, depicting the integration of additional requirements into the product.

The improvements facilitated through direct feedback on different generations of entire prototypes enabled a reduction of the product's complexity on the one hand and ensured haptic as well as functional improvements on the other hand. The product is going to be in mass production and launched to the market shortly.

7 SUMMARY AND OUTLOOK

The integration of “Agile concepts” in product development, particularly in engineering design methods, has proven to be an efficient measure to decrease project risks. This approach is especially applicable and helpful to support projects with high numbers of parties, as even in early phases complete prototypes can be evaluated and deviations from preassigned requirements get instantly evident.

Additional benefits are achievable by further integration of methods of set-based design into the agile processes. This will open up extra potentials in decreasing the project costs, quality and time-to-market, as dispositions for the integration of production knowledge into the prototype concepts can be enforced. The involvement of manufacturing experts into the prototype evaluation enables to compare different options concerning their internal manufacturability and to consider given resources.

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