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Alignment of the change to agile through method-supported evaluation of agile principles in physical product development

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Abstract

Background: Companies in physical product development strive to integrate agile approaches into different organizational units. However, the purposes they are pursuing are very diverse (improve product quality, achieve shorter development times, etc.). While the individual goals are different, the number of agile approaches has increased. Despite the large variety, it has been shown that companies in the field of physical product development are faced with great challenges due to the integration of agile approaches. **Aim**: The challenges of an agile transition are to be facilitated by the situation- and demand-oriented application of agile principles and appropriate factors. **Method**: For this reason, influencing factors on the agile capabilities of companies were identified and clustered in this article. In addition, the factors were assigned to agile principles for mechatronic system development, whose application positively influences the respective factor. **Result**: From this information, a methodology was developed that supports method and process developers in describing the respective situation in which an organizational unit is situated. Based on this, a requirement profile for the method or process solution to be developed is derived from the factor-principles-cluster. **Conclusion**: This methodology enables process developers to develop and apply tailor-made agile practices for the respective organizational unit. This is intended to keep the expected challenges of agile work in physical product development as low as possible.

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Keywords: ASD – Agile Systems Design; Design Research; Agile Product Development

1. Introduction

Current headlines show more than ever how risky and expensive uncertainties can be in mechatronic system development. Examples of the emergence of uncertainty are Trump's trade war with China, which could cause costs of 850 billion dollars [1], legal disputes in diesel lawsuits [2], regulated Brexit or No-Deal-Brexit and whether companies continue to comply with EU regulations, rules and quality standards [3] or the climate crisis, which triggers a radical change in society and affects the capitalist economic system as a whole [4]. These trends have a direct influence on companies and their development processes, as they constantly strive to be economically successful even in changing societies. To be able to face the resulting challenges, companies are adopting agile ways of working [5]. The implementation of agile approaches often triggers a large-scale change process in organizations, because organizations as a whole have to become agile, which also means a transformation of structures, forms of cooperation and in many other areas [6].

However, companies are rapidly confronted with the problem that the majority of agile approaches originate from software development and that proven structures such as process knowledge or valuable product knowledge are not proactively integrated into the development processes through these approaches. Accordingly, agile approaches in a volatile environment offer important opportunities to increase responsiveness in the process, but lack the consideration of essential structuring elements. [7,8]

In order to design a successful change process towards a flexible organization, companies are therefore faced with the

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challenge of combining a suitable degree of flexible and structuring elements in the development process. However, there is no approach that provides the right methods and process solutions for every application. But this is necessary because the users of agile approaches pursue different goals. Sometimes it is intended to increase the speed in the development process, while other companies want autonomous teams or even increased product quality. The objectives pursued with the application of agile approaches are manifold. [9] Since there is no method that meets all objectives, companies need support in the development and adaptation of suitable methods or process solutions for the specific situation. The focus should be on the systematic implementation of agile principles through appropriate practices. This goal is pursued in this article. The result is a methodology that supports process developers in identifying the specific actual state of the application area. From this a weighted requirement profile for the method to be developed which supports the respective use case is then determined with the help of the systematic. This then serves the process developers as a guard rail for further method development.

2. Literature Background

2.1. Context of Product Development

Product development can be abstracted as the continuous interaction of three systems [10]. The resulting system triple describes product development as a continuous cycle of analysis and synthesis activities (see Fig. 1). The operation system (developer, infrastructure, resources, ...) synthesizes the system of objectives on the basis of its state of knowledge. The system of objectives includes the objectives to be achieved by a product, its justifications and interactions as well as requirements and boundary conditions. The analysis of the system of objectives by the operation system creates the solution space, which represents a mental representation of all possible solutions for a certain degree of product maturity. From this solution space, the operation system synthesizes the system of objects, which contains sketches, prototypes and the final product itself. The operation system analyses the system of objects at the respective stage of maturity and thereby acquires new knowledge, which in turn represents the basis for an extension or adaptation of the system of objectives. The system of objectives and the system of objects are connected to each other exclusively via the operation system and are continuously concretized and validated throughout the entire development process. [11]

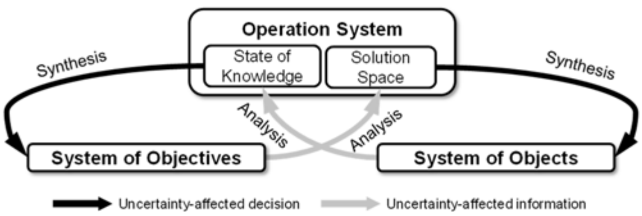

Fig. 1 System Triple of Product Engineering [11]

This understanding allows the iterative representation of product development processes as recurring cycles [12]. The system triple is also suitable for method development. Likewise, this takes place cyclically, with the system of objectives containing a requirement profile for the development method to be created. [13]

Depending on the context, the interaction within the system triple differs with regard to the design of the three systems. The context of product development is subject to a multitude of different influences. HALES AND GOOCH [14] have introduced five levels of resolution (macroeconomic, microeconomic, corporate, project and personnel) that can be applied on an engineering design context (see Fig. 2). This is for the purpose of a more systematic design approach and to provide a disciplined way of thinking and working.

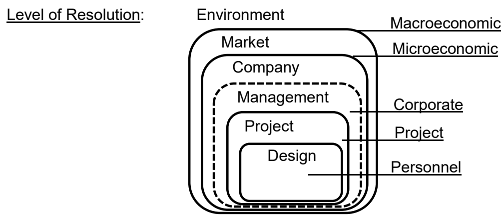

Fig. 2 Scheme for organizing influencing factors [14]

Furthermore, GERICKE ET AL. [15] extended each level with a subdivision of 35 sets of influencing factors all together. As for HALES' level of resolution is the most comprehensive overview from literature and GERICKE's extension give an even more detailed resolution of the product development context, it seems obvious to use this model to structure further research regarding the change process in the field of an engineering design context [15]. In order to address a specific selection of certain factors and to support the process of product development, there is a multitude of process models with different purposes [16]. A model that can be used as an explanatory model for product development is the model of PGE – Product Generation Engineering [17]. According to this model, products are developed in subsequent generations on the basis of references. These references are already existing solutions, sub-solutions, own and third-party products as well as solutions from research and other industries (e.g. first touch screen in the automobile). These references are systematically identified during the development process and correlated within the reference system. The references are then transferred to the generation in development by the three types of variation: carryover variation (carryover of a solution without adaptation), embodiment variation (adaptation of the shape of a solution while keeping the working principle) and principle variation (fulfilment of the function by a new working principle).[18] Principle variation and embodiment variation together form the new development share. Through the systematic categorization of development projects with regard to the new development shares, development risks can be identified and assessed at an early stage. On this basis, resources can be (re-)planned efficiently. [19]

2.2. Agile Product Development

In the dynamic context of product development, companies establish agile approaches in their processes in order to be able to react to unexpected and expected changes [20] in the face of uncertainties. Agility - based on the system triple theory - is the ability of an operation system to continuously check and question the validity of a project plan with regard to the planning stability of the elements in the system triple and, in the case of an unplanned information constellation, to implement a situation- and demand-oriented adaptation of the sequence of synthesis and analysis activities, whereby the customer-, user- and provider-benefits are increased in a targeted manner [21].

Agile development procedures to increase the agility of development teams are particularly established in the field of software development. However, if agile methods such as Scrum or Design Thinking are introduced outside software development, problems occur more frequently [22]. For a sustainable establishment, a cultural change of the organisation to agility must also be taken into account [23]. For this purpose, agile principles are often introduced, which shape the feeling of agility through general basic assumptions [24] but mostly also originate from the field of software development [25]. In order to minimize challenges resulting from the pure application of agile practices in the field of mechatronic system development, traditional approaches are no longer replaced by agile, but rather extended by these approaches [26], which showed promising results in first studies [27].

The ASD - Agile Systems Design offers a systematic combination of traditional and agile development [28]. This approach was developed on the basis of observations in real and successful development projects and is guided by nine basic principles that support development teams in the development of mechatronic systems. These are [28]:

1. *The developer is the center of product development*
2. *Each product development process is unique and individual*
3. *Agile, situation- and demand-oriented combination of structuring and flexible elements*
4. *Each process element can be located in the system triple and each activity is based on the fundamental operators analysis and synthesis*
5. *All activities in product engineering are to be understood as a problem-solving process*
6. *Each product is developed on the basis of references*
7. *Product profiles, invention and business model form the necessary components of the innovation process*
8. *Early and continuous validation serves the purpose of continuous comparison between the problem and its solution*
9. *For a situation- and demand-oriented support in every development project, methods and processes must be scalable*

These principles serve as guidelines to align development actions with them and to identify, develop and adapt practices that support developers in the product development process [28]. Factors influencing agility can be evaluated and integrated context-specifically via these principles.

2.3. Change management in an agile context

MISRA ET AL. [29] state that agile development is not based on the use of individual tools or practices, but on a holistic way of thinking. The change towards agility therefore often requires a change in the entire corporate culture, with leadership and cultural aspects of a company being key factors [30]. When comparing Software and mechatronic organizations EKLUND AND BERGER [31] were able to show from a comparative case study that most of the research on scaling agility in companies can be regarded as generally valid, i.e. independent of the application domain. Accordingly, the correct coordination of integrating practices is equally decisive for the success of Agile scaling in the context of mechatronic system development or software development [31]. For an organization transformation towards agility in a holistic way it has to focus on the unique and sophisticated interplay of operational, strategic or cultural aspects. Therefore, existing practices, models, tools and frameworks related to effective change management need to be supplemented for an agile transformation context. [32]

Change management is defined by INVERSINI [33] as the structuring and control of a planned organizational change processes. For effective change management one of the success factors is the conscious consideration of situational requirements. A change process is considered sustainable if it increases the problem-solving ability of a company in order to be able to react faster and more flexibly to new requirements. INVERSINI says about the evolution of a change process that even during a change project the once chosen change principles should not be rigidly adhered to, but that one has to act flexibly and demand-oriented. [33] This seems to be particularly important in an agile context because several sources state that agile working methods are best introduced after an agile approach, i.e. using “an agile way of implementing agile” [30,34].

3. Aim of Research

Although the number of agile approaches is large and the research activities in this area have also been strongly established for some years, companies from the mechatronic system development with the goal of changing to agile face the challenges that agile approaches bring with them in the development of physical products. The change to agile is carried out on different organizational levels with different specific goals. The number of factors in the development context associated with this change is also high. For this reason, method and process developers often lack transparency about which factors have to be further developed or adapted in which way by a change process to agile. However, this is essential especially for the context of mechatronic system development in order to integrate the agile approaches originating from software development into the physical world in the best possible way. For this reason, our goal in this article is to establish a systematic that supports method and process developers in describing their specific application case through the relevant factors for change to agile. In addition, a combination of these factors with agile principles of mechatronic system development and a weighting of these clusters will be used to build a system of objectives on the basis of which specific methods and process solutions can be generated. The systematic provides process developers with specific guidelines for the development of application-specific methods. The following research questions are answered in the article to operationalize the research project:

1. *Which factors have an influence on agile procedures in product development?*
2. *Which principles for agile mechatronic system development can modify these factors?*
3. *How is a methodology designed that supports method and process developers in deriving the necessary requirement profile for the process solution to be developed for agile product development for their specific application?*

In order to answer the research questions, a broad literature search was carried out with the aim of collecting factors that have an influence on the agility of a company on different organizational units. The aim was to cover the different levels of resolution of HALES AND GOOCH's model [14] by searching for literature in these particular areas (see Fig. 2). In addition, experts from 9 German companies working agile or partially agile as well as representatives from 4 other research locations in Germany dealing with the topic of agility were interviewed at a workshop. The statements of these experts were compiled and coordinated with the results of the literature research. In the next step, attempts were made to establish a connection between the factors and the principles of the ASD – Agile Systems Design and to recognize correlations. This was based on the fundamental assumption that the principles are general and always valid in the mechatronic context, while the factors have context-specific relevance. In order to design the methodology in the final step, various ways of accessing the factors were searched for. The aim should always be to get only relevant factors and not the complete *flood* of information about agility that research has already gathered. The principles of the ASD – Agile Systems Design should also be prepared in such a way that the focus is placed only on the most important principles for the current development context. The principles should serve as guidelines and create a better understanding of the system of objectives, while the factors should point out fields of action that are to be understood as suggestions for targets.

4. Results

4.1. Factors influencing agility

By literature research (see 0) and the evaluation of the results of the expert workshop (see Appendix A [E]) over 200 factors could be identified, which have an influence on the agility of an organizational unit (team, project, department, etc.). In this sense, everything that can have an influence on agile procedures (positive or negative) in the context of mechatronic product development was considered as a factor, such as best practices, methods and tools, certain equipment, premises, competencies, organizational principles, hierarchies, leadership styles, emotions and many more. Some examples of factors are given below: *Helping people to help themselves: The development team is supported by the management in the process as well as in decisions made within the team* [6,34,35,42] in *2-2 Management style* or *Regular delivery of new increments: The development team is expected to deliver new increments on a regular basis within your project, with small increments being preferred so that the validation of the results and feedback from the customer is as continuous as possible* [6,35–37] in *3-2 Project management* or *Courage, openness and self-confidence: Employees should have the courage to make their own decisions, the openness to share them transparently within the company (or with all those involved) and the self-confidence to fight for and stand up for their own decisions* [expert workshop] in *4-5 Motivation and emotion* (see 0).

In order to structure and cluster these factors, the framework for describing the development context according to GERICKE [15] was used in a slightly adapted form. Thus, all factors could be clearly assigned on two levels. At level 1, only the groups *Company*, *Management*, *Project* and *Personnel* were included and the originally existing groups *Macroeconomic* and *Microeconomic* were not further considered because all the factors identified at these levels are not actively influenceable by the company itself. At level 2, 32 subgroups exist in the adapted form (see Appendix), with some of GERICKE's original groups being changed or replaced by name respectively extended. Thus, the level 2 group *Validation System* relevant for agile product development processes was created in the cluster *Company*, the level 2 subgroup *NPD* was renamed *PGE - Product Generation Engineering* and in the cluster *Project* the level 2 subgroup *Production* was removed, but the groups *Prototyping* and *Validation* were added. It has to be noted that at the current state of work on some level 2 subgroups, relevant statements regarding their influence on agility could not be identified neither in the literature nor in the workshop. The extended framework therefore only contains factors that have a direct influence on the agile work of organizational units and not the factors that describe the overall context. The factors serve in the later application of the method as a kind of catalogue, in order to support method and process developers in the identification of the factors relevant in the specific context for the change to agile.

4.2. Assignment of the factors to the principles of ASD - Agile Systems Design

For later adjustment and positive influencing of the factors, these were assigned to the ASD basic principles. If, in the later and specific application of the method, the basic principles identified as relevant are operationalised by a process solution, the assigned factors are influenced. In order to facilitate the allocation, all effects resulting from complying with the principles of ASD - Agile Systems Design were initially derived in the retrospective analysis of 20 product development projects [38], but do not claim to be complete. To give an example, the following effects were assigned to be activated in product development by following the first ASD principle *The developer is the center of product development*:

- High motivation and high commitment of employees
- Lifelong learning
- Harmonious and intensive cooperation
- High efficiency and creativity of employees

- Autonomous employees
- Employee-oriented management
- Targeted provision of knowledge and resources
- Competence- and demand-oriented use of methods, tools and processes
- Principle serves as a guideline and requirement for method research and development

In addition, the known effects of collected factors from literature and expert workshops were considered and compared with the principles of ASD - Agile Systems Design. If a positive contribution of an effect resulting from the respective factor to the individual effect of the various ASD basic principles was expected, a factor was assigned to the corresponding principle. For example, the above-mentioned factor *Incremental development* has been assigned to the principles 3 *Agile, situation- and demand-oriented combination of structuring and flexible elements*, 4 *Each process element can be located in the system triple and each activity is based on the fundamental operators analysis and synthesis* and 8 *Early and continuous validation serves the purpose of continuous comparison between the problem and its solution*. By assigning the factors to the ASD principles and to the level 2 subgroups of the framework, the principles were also assigned to the groups (see Appendix).

With this allocation it was noticeable that each of the factors could be assigned to at least one principle. In addition, it was found some principles have a significantly higher number of assigned factors than others. For example, the 1st ASD principle - *The Developer is the Centre of Product Development* - has the most assigned factors. However, it should be considered that the individual factors are neither weighted nor relevant in every situation, which is why no rules can be derived from them.

In the following, the **variable $\boldsymbol{n_{g.s,p}}$** is introduced to represent the number of factors relevant in various contexts, the contexts being specified by the indices *g*, *s*, and *p*.
Explanation of the indices:

g: Indicates the **level 1 group** that is being considered
s: Indicates the **level 2 subgroup** that is being considered
p: Indicates the **ASD-principle** that is being considered

Examples (compare with 0):

n_3 = total number of factors in third group (level 1) *Project*.

$n_{3.4}$ = total number of factors in the fourth subgroup (level 2) *Team output* within the third group (level 1) *Project*.

$n_{3.4,\,1}$ = total number of factors in subgroup *Team output* that have been assigned to the 1st ASD-principle *The Developer is the Centre of Product Development*.

By simply counting the number of factors assigned, a *factor quantity matrix* ($n_{g.s,p}$-table, see Fig.5) can be created that reflects the number of factors in the previously displayed contexts. This matrix helps to get an overview, which principles in certain contexts (level 1 and level 2) can contribute valuable factors for a successful agile transformation.

4.3. Presentation of method implementation

Since not all of the identified factors are relevant for each organizational unit and for each change to agile, it is important to identify the factors that need to be optimized or changed in the particular situation in order to achieve the intended goals with the respective change to agile. However, in order to find the appropriate factors for the respective situation, the large number of factors must first be targeted and systematically limited. This is supported by the nine principles of ASD - Agile Systems Design. They serve as guidelines to be able to evaluate holistically which factors should be included in the system of objectives for change management in order to achieve the right degree of agility and to convey the effects which are aimed at by these factors.

To achieve this goal, a methodology has been developed to support:

- the identification of the actual situation of a company or organizational unit
- the identification of appropriate fields of action for the change to agile
- the proposal of appropriate factors
- the prioritization of the nine principles of ASD - Agile Systems Design for the case of the user.

This methodology is applied via a tool that creates a system of objectives for change management by interacting with the user. The following procedure was formulated for this purpose:

- **Step 1** – Set the focus on a certain group (level 1): The user is asked to perform a binary comparison between the level 1 groups (cf. dominance pair comparison according to BORTZ ET AL. [39]). In this comparison, he must always decide which group has the greatest potential for improvement in agility for the company's situation. When the comparison is complete, only the level 1 group with the highest value is passed to the next step (see Fig. 3).

	1 Company	2 MGMT	3 Project	4 Personnel	Sum
1 Company		0	0	1	1
2 MGMT	1		0	1	2
3 Project	1	1		1	**3**
4 Personnel	0	0	0		0

Fig. 3 Example of a binary comparison at level 1 and subsequent transfer of the highest rated group (here *Project*).

- **Step 2** – Prioritization of fields of action via subgroups (level 2): Here the user is again asked to make a binary comparison, this time between all level 2 subgroups that inhabit the given level 1 group (see Fig. 4).

		Subgroups of *Project*									Sum	$w_{g.s}$
		3.1	**3.2**	**3.3**	**3.4**	**3.5**	**3.6**	**3.7**	**3.8**	**3.9**		
Subgroups of *Project*	**3.1**		1	0	2	2	1	1	0	1	**8**	**6,67**
	3.2	1		1	2	2	1	2	1	1	**11**	**9,17**
	3.3	2	1		1	1	2	0	0	1	**8**	**6,67**
	3.4	0	0	1		1	2	0	0	0	**4**	**3,33**
	3.5	0	0	1	1		0	1	0	0	**3**	**2,5**
	3.6	1	1	0	0	2		1	0	1	**6**	**5,0**
	3.7	1	0	2	2	1	1		1	1	**9**	**7,5**
	3.8	2	1	2	2	2	2	1		0	**12**	**10,0**
	3.9	1	1	1	2	2	1	1	2		**11**	**9,17**

Fig. 4 Binary comparison at level 2 and weighting of subgroups.

The result of this comparison is not to exclude groups this time, but to weight all subgroups. The unitless **weighting value** of a subgroup is expressed in the following by $\boldsymbol{w_{g.s}}$ (index notation as above). If a subgroup reaches a particularly high value, the user recognizes the greatest potential for improvement there. This weighting (see Fig. 4, right column) is transferred to the next step.

- **Step 3** – Prioritisation of the principles of ASD – Agile Systems Design for the case of the user: The transferred weighting values $w_{g.s}$ of each subgroup are multiplied with the corresponding matrix cells of the *factor quantity matrix* or $n_{g.s,p}$-table (see 4.2) if the indices $g.s$ match. If you form the column sum of each rows, you get a situation-specific evaluation of the relevance of each individual ASD principle (see Fig. 5). These situation-specific relevance values serve the user as a hierarchy of the principles that are most important to him and on which the change process should be oriented.

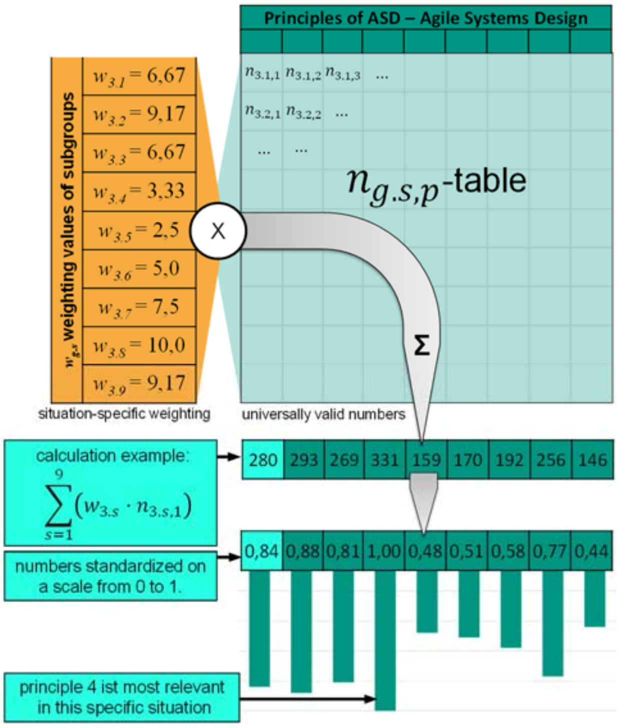

Fig. 5 Calculation of situation-specific relevance values.

- **Step 4** – Provision of a list of suitable factors and further information: The tool creates a list of factors that most likely fit the user's situation and should be optimized. For this purpose, the factors of the level 2 subgroups with the highest weighting and the greatest agreement with the ASD principles of the highest relevance value are listed first (see Fig. 6). From this list, the user can select factors according to his needs and his own final assessment, on the basis of which precise goals and requirements for the change process can be formulated. Based on the selected factors and with the help of the principles of the ASD - Agile Systems Design sorted by relevance, the user can now formulate the system of objectives for the change process.

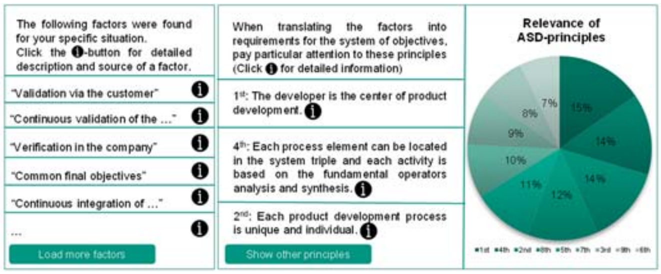

Fig. 6 Exemplary list of selected factors and principles sorted by relevance.

What exactly such a system of objectives looks like is in turn up to the company or is the original task of the company management. However, since target setting itself is regarded as an iterative and participatory process [40], the tool and the implementation of the steps mentioned is an activity that can also be carried out by several persons relevant to product development.

In summary, the tool helps you to identify situation- and demand-specific fields of action by indicating the appropriate factors influencing agility and by weighting the ASD principles for a focused orientation of the goals in the change process.

5. Discussion

As Eklund and Berger [31] already stated in reference to large-scale agile development, there is no patent recipe, but rather the alignment of a large number of integrating practices is crucial to the success of agile scaling in enterprises. This research starts there and aims at identifying the multitude of factors influencing agility in mechatronic system development and making them operational under the holistic approach of ASD - Agile Systems Design. The total number of factors is very high and for different change processes to agile different sections of these general factors are relevant with regard to influencing the individual development context. These factors should be revealed to users according to their needs and be adapted or extended with the help of the principles of ASD - Agile Systems Design.

The tool designed for this purpose should help to quickly determine the actual situation of a company or organizational unit and to identify fields of action that can be used to formulate a system of objectives for change to agile. Although the tool supports the formation of the system of objectives for the specific change to agile, the assignment of the factors to the ASD principles was subjective and requires further validation. In addition, the factors are currently all equally weighted, which is why the option of a predefined factor weighting will be discussed in future work. The factors also already cover a large part of the influences on agile work in physical product development but are by no means complete. By applying the tool iteratively, the *agile way to implement agile* [30,34] will increase the probability of a successful and sustainable transformation.

It should also be mentioned that the tool has not yet been tested in a real environment but only with agile experts who have evaluated the tool regarding usefulness, completeness and applicability. This initial evaluation of the tool has already shown that the methodology is working and systematically supporting the user. However, what influence the use of the tool has on the change process of a company still requires research. Furthermore, the tool only supports the derivation of a requirements profile for an agile transition or methods to be developed, but not yet the final implementation.

The added value provided by this research work lies in the fact that, on the one hand, an understanding of the divergent interrelationships of different influencing factors in different hierarchies of an organization with its agile capabilities has been built up. On the other hand, a possibility was created for practice to build up individual agile methods, so that companies no longer must establish processes that do not fit their requirements and needs.

6. Conclusion and future Works

Since there is no agile approach for mechatronic system development that enables every company to achieve their specific goals in the context of agility, a methodology has been developed in this article that supports developers in creating individual agile methods and process solutions. This method is not intended to support the product development process itself, but to be an enabler for a successful agile transformation. More than 200 factors from literature and expert opinions were collected, which have a possible influence on the agile capabilities of an organizational unit. These serve in the methodology as a kind of catalogue, which enables the developers to understand their own situation in the best possible way. For this purpose, the factors were assigned to the 9 basic principles of ASD - Agile Systems Design and likewise assigned to different organizational fields of action. By assigning the factors to agile principles, the factors can now be influenced in a targeted manner and interpreted according to requirements. Using a tool, developers can now achieve an intuitive weighting of the factors and can identify which basic principles of ASD - Agile Systems Design can best support them in their respective situation. This enables them to create a requirements profile for a specific method or process solution to be developed.

In the future, the list of factors will be continuously reviewed for completeness. In addition, the resulting methodology will be used in future research work to generate specific agile methods for mechatronic system development. It is subject to continuous evaluation and its maturity level is successively increased.

Appendix A.

Grp. Lv1	Subgroup Level 2	Factors with an influence on the agile capabilities of an organization's action system	References	Basic principles of ASD – Agile Systems Design								
				1	2	3	4	5	6	7	8	9
1 Company	1.1 Branch	Influence of product life cycle time	[41]		x	x			x	x	x	
		Influences of the normative world	[E]		x	x						x
	1.2 Corporate structure	Hierarchies in the company	[42]	x								x
		Clear and short decision paths	[43]	x								x
		Scaling agile practices	[44]		x			x				x
		Collaboration within the company	[45,46]		x					x		
	1.3 Corporate system	Adherence of working hours	[36]	x								
		Improvement of corporate standards	[47]		x							x
		Sustainable implementation of Agile	[48]	x	x	x						
		Coaching and training of employees	[34,49,50]	x	x				x			
		Good provision of information	[51]	x			x		x		x	
		Implementation of methods through training courses	[49]	x				x				
		Expansion of creative freedom	[52]	x					x	x		
		Agile teaching and training concepts	[E]	x			x					
		Use of agile coaches	[50]	x								x
		Illustration of agility in standards & guidelines	[E]	x								x
		Autonomy through borders	[53]	x								x
		Cross-divisional coding standards	[36,54]	x								x
		Balanced salary levels	[55]	x								x
	1.4 Corporate strategy	Strategy aligned to customer benefits	[56]							x		
		Market observation	[35]							x		
		Authority of the customer	[56]							x		

Lv1	Lv2	Factor	Ref	ASD Principles								
				1	2	3	4	5	6	7	8	9
1 Company	1.4 Corporate strategy	Consideration of business case and product profile	[E]		x		x		x	x	x	
		Avoidance of standard contracts and pre-specifications	[44,57]		x				x			x
		Management of a virtual product portfolio	[58]		x					x		
		Common understanding of success criteria	[35]		x					x	x	x
		Fluidity of resources	[59]			x	x			x		
		Openness towards product variation	[45]				x		x	x		
		Integration of suppliers and partners	[46,47]						x		x	
		Top-down agreement on procedure	[E]	x								x
		Coordination between software and hardware components of technical systems	[60]						x		x	
	1.5 Corporate culture	Company-specific understanding of agility	[46,61,62]	x	x							
		Shared metamodel for process design	[46]	x	x	x		x				x
		Distinct error culture	[34]	x	x	x	x				x	
		Communication between agile and traditional organizational units	[44,46]	x	x	x						x
		Rough planning instead of micromanagement	[E]	x	x	x						x
		Avoidance of waste	[6,35,63]	x	x			x				
		Rather pragmatics than dogmatics	[63]	x	x			x				x
		Communication between development teams	[46]	x		x	x					x
		Lifelong learning	[34]	x			x		x			
		Uniform modelling approaches	[44]	x				x				x
		Direct flow of information within the company	[35]	x								x
		Common visions and values	[34,35]	x								x
		Open conflict culture	[64]	x								x
		Maximize knowledge through validation	[E]		x				x		x	
		Interdisciplinary system development	[45,46]	x		x	x				x	x
		Quick exchange of new ideas	[65]				x				x	
		Continuous synchronization between hardware and software	[66]				x				x	
	1.6 Production	Low conversion effort for production systems	[67,68]									x
		Versatility of the production system	[67,68]									x
		Adjustment range or adjustability of the production system	[67,68]									x
		Variety of loads	[67,68]									x
		Substitutability in the production system	[67,68]			x						x
		Manageable variety of parts of the production system	[67,68]								x	x
		Partial commonality of products	[67,68]						x			x
	1.7 Stakeholder	Agile oriented condition management	[E]		x	x				x		
		Involvement of internal and external stakeholders	[69]				x		x	x	x	x
		Integration of customers, suppliers and users	[35,70]						x	x		
		Regulated cross-company collaboration	[E]		x	x				x		x
	1.8 Supplier	Short response time to inquiries	[71]								x	
		Networks and partnerships	[46,72]	x					x	x	x	x
		Unscheduled orders to suppliers	[73]		x	x					x	
		Evaluation of service providers	[46,74]		x				x		x	
		Agile supply chain instead of mass production	[75]		x							x
		Large number of possible suppliers	[76]		x							x
		Short delivery times	[77]			x	x				x	
		Compatibility of used subsystems	[E]						x			x
		High availability of resources	[77]				x				x	

Lv1	Lv2	Factor	Ref	ASD Principles								
				1	2	3	4	5	6	7	8	9
1 Comp.	1.8 Supplier	Choice of company location	[78]						x		x	
	1.9 Validation system	Validation system developed by product developer	[E]	x							x	
2 Management	2.1 Shared values	Uniform understanding of the problem	[79]					x				
		Significance of changes	[34]	x			x					
		Communication openness of all participants	[6,35,80]	x					x	x	x	
	2.2 Mgmt. style	Intuitive processes in everyday working life	[35]	x								
		Psychological empowerment	[53]	x								
		Create and maintain Commitment	[57,81]	x								
		Helping people to help themselves	[6,34,35,42]	x	x	x						
		Empowerment of employees	[6,53]	x	x							x
		Adaptive leadership style	[82]	x			x					
		Generalists in the development team	[35]	x					x	x		x
		Employee-centered understanding of leadership	[47]	x								x
		Optimize working environment and reduce distractions	[35]	x								x
		Balance between demanding and encouraging employees	[E]	x								x
	2.3 Mgmt. skill	Agile oriented project management	[E]	x	x							
		Agile knowledge at management level	[44,46]	x								x
	2.4 Mgmt. staff	Willingness to change	[57]	x	x	x			x			x
		Good moderation skills	[6]	x	x							x
3 Project	3.1 PGE	Cross-industry availability of reference elements	[83]						x			
		Maintaining the knowledge base	[35,84]	x	x				x			
		Documentation in the right scope	[48]			x	x	x			x	
		Newly developed shares of new product are deliberately determined	[85,86]			x			x			
		Systematic search for references	[83]					x	x			
	3.2 Project management	Iterative process design	[47]			x						
		Consideration of planning stability	[8]							x		
		Sufficient resources for financial hedging	[E]									x
		Improvement of processes	[6]	x	x			x				
		Common final goals across all levels	[34]	x	x					x		
		Counteract lack of time for creative idea generation	[E]	x			x	x	x			
		Living project management	[87]		x	x						
		‘Good Enough' planning	[46,88]		x	x	x	x				
		Lead process and standards that allow agility	[89]		x			x				
		Risk tracking	[35,90]		x			x	x			
		Regular delivery of new increments	[6,35–37]			x	x				x	
		Transparent budget controlling	[46,91,92]			x	x			x	x	x
		Consideration of project length	[93]			x				x	x	
		Creation of product profiles	[94]				x		x	x	x	
		Adaptivity of the target system	[95]				x					
		Analysis of the project risk	[46,86,90]						x	x		
		Planning meetings with customers	[36]		x	x	x			x		
		Involvement of new stakeholders	[35]			x			x			x
	3.3 Design team	No hierarchy in the team	[55]	x								
		Autonomy of the team	[6,35,96]	x								
		Flexible allocation of roles in the team	[46,97]	x								

Lv1	Lv2	Factor	Ref	ASD Principles								
				1	2	3	4	5	6	7	8	9
3 Project	3.3 Design team	Adaptation of the team	[113, E]		x	x		x				x
		Team Guide Board	[35,98]	x								
		Regulated discussion culture	[99]	x	x							
		Reflection in Team Retrospectives	[6,35]	x	x	x						
		Regular team meetings	[96]	x	x	x	x					
		Decision-making power for individual team members	[100]	x	x	x		x				
		Different type profiles in the team	[101]	x					x			
		Suitable team size	[96]	x								x
		Team has a mission statement or team vision	[6]	x						x		x
		Team cohesion	[6]	x								
	3.4 Team output	Constant team performance	[102]	x								
		Internal team performance measurement	[102]	x								x
		Short release cycle times	[35,96]			x				x	x	
	3.5 Working environment	Intuitivity of tools	[E]	x								
		Task board or dashboard visualization techniques	[103]	x								
		High availability of supervisors and stakeholders	[E]	x	x							
		Availability of work equipment	[E]	x	x	x						x
		High project visibility	[6,46,104]	x	x		x					
		Targeted access to tools and methods	[105]	x	x			x				
		Targeted access to knowledge	[105]	x	x				x			
		Locations optimized for information flow	[80]	x	x							
		Cross-party method usage	[E]		x			x				
		Access to additional premises	[E]	x	x							x
		Low interaction between mechanics, electronics and computer science	[66]						x		x	x
		Presence of the customer in the development process	[36,56,70]							x	x	
	3.6 Design task	Coevolution of objectives and objects	[95,106]				x					
		Development aligned to product profile	[94]							x		
		Allow and greet later changes	[57,107,108]	x			x			x	x	
		Low interface complexity	[66]	x					x			x
		Evaluation of the criticality of projects	[46,91]		x		x		x	x		
		Clear prioritization of requirements	[35,88]			x	x			x	x	
		Avoidance of mutual dependencies	[E]				x		x			x
		Maintenance of the target system	[95]				x			x		
		Result orientation through 'Definition of Done'	[109]	x			x			x	x	
		Stick to a simple designs	[36]				x					
		Test-first development	[36]					x	x		x	
		Knowledge about description possibilities of products	[110]		x	x	x					x
		Knowledge about description possibilities of tasks	[110]		x	x	x					x
		Contract models that allow agility	[57]		x							x
		Acting in the interests of the customer	[E]		x				x	x	x	
	3.7 Use of design tools and methods	Applicability of development methods	[15]	x								
		Use of methods with reasonable effort	[15]	x	x							
		Visualization of the project progress	[35]	x	x		x	x				
		Intuitive preparation of methods	[15]	x	x			x				
		Whiteboard Modelling	[37]	x			x				x	
		Diversity of tools and methods	[E]	x				x				x
		Low degree of formalization of the process model	[111]		x	x		x				x

Lv1	Lv2	Factor	Ref	ASD Principles								
				1	2	3	4	5	6	7	8	9
3 Project	3.7 Use of design tools and methods	Correct use of user stories	[46,95]		x		x			x		
		High level of detail of the process model	[111]		x			x				
		Adaptivity of the process model	[111]		x			x				
		Versatility of virtual simulation methods	[112]				x				x	
		Uniform problem solving process	[113]					x				x
		Adequate level of abstraction of methods, ways of thinking and processes	[15]					x				x
		Possibility of adapting methods, ways of thinking and processes	[15]					x				x
		Knowledge of work organization and project management elements	[110]		x	x						x
	3.8 Prototyping	Fast prototype and component production	[114]								x	
		Prototyping at overall system level	[115]							x	x	
		Versatility of physical prototyping techniques	[114]								x	x
	3.9 Validation	Easy access to feedback from experienced users	[37]	x					x	x	x	
		Constant verification in the company	[12]				x					
		Early and continuous validation of the SiD	[35]								x	
		Validation via the customer	[56]				x			x	x	
		Correct and continuous integration of subsystems	[36]				x				x	
		Continuous validation of the development process	[12]				x				x	
		Change validation mode according to the situation	[116]								x	x
4 Personnel	4.1 Knowledge	Detailed technical instruction	[117]	x					x			
		Preserving and contributing experience and knowledge	[E]	x	x	x			x			x
		Distinctive professional competence and expert knowledge	[118]	x					x	x		
	4.2 Skills and competencies	High social competence	[118,119]	x								
		Emotional stability	[119]	x								
		Good drawing and sketching skills	[103]	x								
		Quick comprehension	[120]	x								
		High assertiveness	[119]	x								
		Working according to the flow principle	[6,118,121]	x								
		High creativity potential	[118]						x			
		Strong heuristic competencies	[120]	x	x			x				
		High method competence	[118]		x			x				x
		High potential for elaboration	[118]			x	x				x	
		High problem solving competence	[113,122]					x				x
		Concepts of customer-developer communication	[36]		x		x		x		x	
		Existence of agile basic competencies	[123]	x		x						x
	4.3 Individual styles of thinking & acting	Diversity in employee composition	[6,101]	x					x			
	4.4 Attitude	High commitment of the team	[57,81]	x								
		Intensive teamwork	[45]	x								
		Direct communication channels in the team	[35,71,124]	x								
		Short response times and high availability of colleagues	[E]	x								
		High exchange of knowledge within the team	[35,37]	x								
		Conviction of the use of methods	[E]	x								
		No feeling of additional administrative effort	[E]	x	x							
		Respectful interaction with each other	[119]	x								
		Reasonable expectations of agile working practices	[44]	x								
		Courtesy and kindness	[125]	x								

Lv1	Lv2	Factor	Ref	ASD Principles								
				1	2	3	4	5	6	7	8	9
4 Personnel	4.4 Attitude	Open-mindedness towards new methods	[34]	x								x
		Transparency without a feeling of paternalism	[126]	x	x							x
		Willingness to change	[123]	x	x							
	4.5 Motivation, emotion	Feeling of self-determination and influence	[53]	x								
		Motivation and joy in experimenting with changes	[6,35]	x		x	x				x	
		Recognition and appreciation of work	[E]	x								
		Courage, openness and self-confidence	[E]	x								
	4.6 Perfor-mance	Constant employee performance	[102]	x								
	4.7 Output	Verification of work results	[126]	x							x	x
		Results are collective property of the development team	[36, 37, 44]	x								x
		Early and inexpensive failures	[E]		x		x				x	
	4.8 Relation-ships	Self-organisation of responsibilities	[46,127]	x		x						x
		Shared responsibility and mutual commitment	[97]	x								x

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