IDENTIFICATION AND CLASSIFICATION OF UNCERTAINTIES AS THE FOUNDATION OF AGILE METHODS

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ABSTRACT

To remain competitive, companies today are increasingly faced with the challenge of reacting adequately in dynamic development environments. For product development, in particular, it is necessary to organize decision-making processes so they can react quickly and flexibly to changes in the development environment. To describe the dynamics and changeability, the term VUCA is used, which is a synonym for volatility, uncertainty, complexity, and ambiguity, and thus summarises the most diverse forms of changeability. An adaptation of agile methods to the development context makes it necessary to specify the causes of uncertainty in more detail. The article presents a framework that analyses these influencing factors and differentiates them more precisely to specify problems in dealing with VUCA and to develop recommendations for action for the goal-oriented adaptation of agile methods.

Keywords: Agile product development, Agile methods, Organisation of product development, Teamwork, Uncertainty

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1 INTRODUCTION

In order to maintain competitiveness, today companies are increasingly faced with the challenge of building capabilities and competencies to respond adequately in dynamic development environments. For product development in particular, there is a need to organise decision-making processes in such a way that they can react quickly and flexibly to changes in the development environment. To describe the dynamics and changeability, the term VUCA is used, which is a synonym for volatility, uncertainty, complexity and ambiguity, and thus summarises various forms of changeability. Agile working methods are increasingly being used in the development of mechatronic systems as a solution for dealing with VUCA conditions (Michalides et al., 2022). According to Böhmer et al. (2015), agility is understood as the ability to react and adapt to expected as well as unexpected changes in a dynamic environment, constantly and quickly. The resulting characteristics, speed of reaction and flexibility, enable emerging changes to be used as an opportunity (in terms of customer satisfaction, development efficiency and competitive edge) and thus as an advantage.

Agile methods have their origin in software development, where they are primarily intended to create more freedom for the software developer to focus on the actual programming by using a clever project organisation (Dybå and Dingsøyr, 2008). The most well-known methods include Scrum (Schwaber and Sutherland, 2013), eXtreme Programming (Beck, 2000), Kanban (Anderson, 2010) and Design Thinking (Brown, 2009). In particular, they stand for incremental and high-frequency iterative procedures. Furthermore, they force the production of experienceable prototypes within up to 4 weeks, which are tested and evaluated by the customer. Afterwards, the customers give the developers immediate, resilient feedback for the next iteration step (Schmidt et al., 2017). A significant difference to traditional development approaches is the self-organisation of the project team.

Today, the methods are also used in the development of mechatronic systems, but some adaptations were necessary here. Initially, the agile methods were based on domain-specific assumptions from software development, which manifested themselves in the used procedures and tools and therefore required adaptation for use in the development of mechatronic systems (Atzberger et al., 2019). Agile methods were initially designed for so-called sweet spot conditions: This describes the situation in which relatively complete development tasks can be solved in small teams with a similar technical background (Kruchten, 2004).

Mechatronic systems, on the other hand, are large complex systems. In order to develop them efficiently, the division of labour is necessary, so that the development tasks are distributed across several teams with different expertise. The resulting constraints of scale require the adaptation of agile methods, which led to scaled approaches such as Scale or Less (Dingsøyr and Moe, 2013). Another necessity for the adaptation of methods results from the fact that mechatronic systems, in contrast to software systems, must "materialise". This results in constraints of physicality (Schmidt et al., 2017), which make a fundamental adaptation of methods necessary (Atzberger et al., 2020).

The necessity to adapt methods also results from the fact that development contexts of companies vary significantly (Gericke et al., 2013). These are influenced by exogenous factors (market, industry, competitive situation) as well as endogenous factors (corporate strategy or development organisation) (Stelzmann, 2011). The need for context-specific adaptation is also recognised by the industry (Atzberger et al., 2020). However, there are currently no strategies on how and according to which criteria such an adaptation should be carried out. Method adaptation follows different influencing factors. Methods must be integrated into the processes of the development organisation and the company-specific development structures (Paetzold, 2022), but this is not the focus here. Agile methods are used to work in a more goal-oriented way under VUCA conditions, i.e. to react quickly and flexibly to changes. Accordingly, it is obvious to determine the adaptation and selection of methods based on which changes and uncertainties are typical in the context. However, it seems necessary to further differentiate the factors behind the VUCA term, which is usually used generically. In practice, it seems helpful to also consider typical causes of VUCA in method selection and adaptation.

The aim of this paper is to derive a framework by differentiating the terms of VUCA in order to specify changes and uncertainties more precisely and, building on this, to develop a basis for recommendations for action in dealing with them. The following research question therefore forms the basis for the following presentations: How can VUCA factors be differentiated in terms of causes and

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resulting challenges in order to be able to assign their effects on the development process or the decision-making situation?

2 METHODOLOGICAL APPROACH

The basis for the development of the framework is an extensive literature research in which, on the one hand, the keywords volatility, uncertainty, complexity and ambiguity were not searched for in the context of agility. On the other hand, explanatory approaches and definitions for the terms mentioned were analysed from various disciplines (economics, social sciences, systems engineering, engineering sciences and here especially product development). In addition to the broad literature research, the results of a series of studies on the use of and challenges in the application of agile methods for the development of mechatronic systems in German-speaking countries can be used.

3 EXPLANATION AND ANALYSIS OF TERMS

In order to be able to apply agile methods away from software development in a goal-oriented and context-specific adapted manner, uncertainties must be identified and correctly assigned. However, for a proper classification, the corresponding terms must first be defined. Therefore, in this chapter, the components of the VUCA concept are fundamentally explained, analysed and their definition concretely clarified. In this context, the ambiguity and the partially divergent use of the terms, because they are undefined, will be cleared up and their interdependencies and interactions addressed and described. The aim is to assign the terms to development activities and thus to work out the effects, causes and resulting problems for the development.

3.1 Volatility

Volatility basically describes the situation that boundary conditions for an object of observation change permanently, which leads to corresponding changes in behaviour or structure. In business administration, a situation is described as volatile if it is unstable and unpredictable (Mack and Khare, 2016). The reason for this does not necessarily have to be that the situation is complex. Rather, the considered situations can be described clearly and unambiguously, but are very sensitive to external influences. Individual factors can certainly lead to volatility, for example when commodity prices vary strongly. This is more of a statistical problem, which can be treated as an aleatory uncertainty. Accordingly, the need for change is not predictable, but strategies can be derived for dealing with the fluctuations, making them controllable (Bennett and Lemoine, 2014).
Volatility thus refers to turbulences that are determined by the intensity and length (or distances) of triggering events (Waller et al., 2019). Turbulence can also arise as a result of changing boundary conditions, which may challenge or change effective relationships within the considered system. In terms of describing the effects of volatility, this is accompanied on the one hand by a detection problem, since these changes in cause-effect relationships must first be identified. On the other hand, this results in a knowledge problem, because cause-effect relationships may not be known and must first be developed (Bennett and Lemoine, 2014). Causes and effects of volatility are summarised in Figure 1.

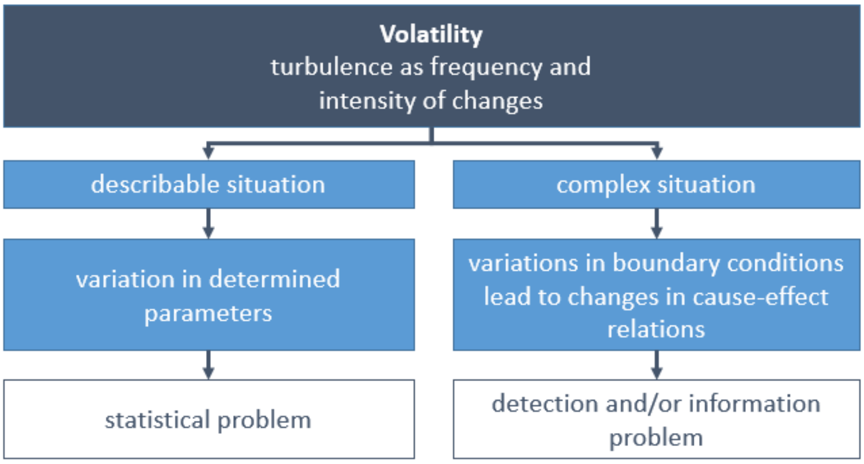

Figure 1: Causes and effects of volatility

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3.2 Uncertainty

Development processes are per se characterised by uncertainties. On the one hand, these result from the fact that the development is based on target descriptions that only become concrete in the course of the development. Solution approaches are only defined during the process, which concretises the further procedure. Not least, uncertainties also result from the fact that complex mechatronic systems are developed in a division of labour. This enables development teams to work in parallel on different development tasks, which must then be integrated into the overall solution. Since the subtasks are not independent of each other, there are procedural, formal and organisational interfaces in the information flows, which are associated with development breaks and lead to corresponding uncertainties in the availability of information (Paetzold, 2022). Awareness of uncertainties in product development is correspondingly pronounced, which manifests itself in extensive publications that are usually based on explanations of terms that are based on interpretations and viewpoints from different disciplines (Thunnissen, 2003).

In mathematics, uncertainty serves as a measure of probability, which allows it to be treated as a statistical problem. In the engineering sciences, the term is often associated with uncertainty and lack of transparency, which leads to inaccuracies in the design of products (Engelhardt, 2013). In some works, the focus is primarily on exactness, e.g. of quantities to be measured, which corresponds to the mathematical interpretation of uncertainty. In the context of risk management as an associated process to product development, uncertainty is defined as a condition resulting from the complete or partial lack of information or knowledge (DIN EN ISO 31000, 2018). The cause of uncertainty is understood to be a lack of information availability, regardless of the basic perspective (DeLaurentis and Mavris, 2000), whereby the causes of missing information are caused by the characteristics of the development process, but can have very different effects (Paetzold, 2022).

Given this background, the differentiation between aleatory and epistemic uncertainties appears helpful in describing the causes and effects of uncertainties in more detail. Aleatory uncertainties are those that arise due to random variations of influencing variables. Epistemic uncertainties, on the other hand, are those that occur when there is no precise knowledge of the considered object or when there is a lack of knowledge. Thunnissen (2003) further differentiates uncertainties here on the basis of extensive analyses of understanding in different disciplines. As a result of the analysis, he clusters various causes of uncertainties and then assigns them to the criteria epistemological and aleatory. This creates the basis for locating types of uncertainty more concretely in the development process itself. This description of causes seems very suitable for deriving strategies on how to deal with them in the context of agile working. This is based on the assumption that aleatory uncertainties are rather connected with an information problem, while epistemic uncertainties are connected with a knowledge problem. The following figure 2 presents a visual summary and a categorisation of the formulated interrelationships.

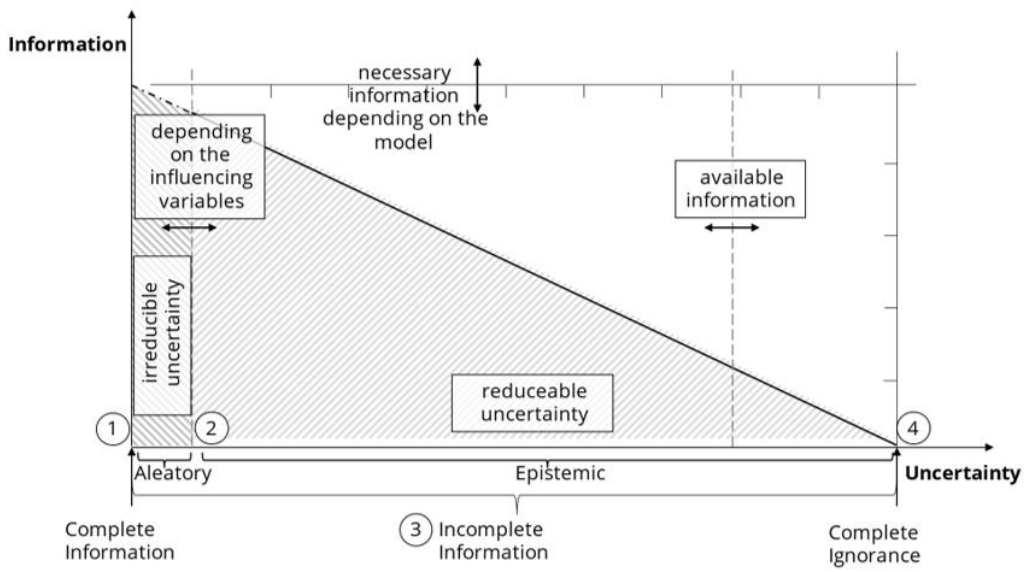

Figure 2: Categorisation of uncertainties (Knetsch, 2004)

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3.3 Complexity

Complexity is generally understood as the possibility of mentally grasping and controlling a system (Ulrich, 1970). The concept of complexity is based on the concept of a system, according to which a system consists of a number of elements that are connected to each other via relations (Patzak, 1982). This creates a wealth of relationships not only between the elements themselves but also with the environment, which is also manifested with a high degree of changeability (i.e. variability) and/or a multitude of states (i.e. dynamics) (Patzak, 1982).

A system is described as complex if its elements and/or relations can no longer be grasped or understood, so that a complete description of the structure and behaviour of the system is not possible (Rohpohl, 2009). The system can then develop emergent behaviour, i.e. system behaviour that was not thought of in advance (e.g. Osmundson et al. (2008). Thus, in a sense, complexity has an objective character and indicates a knowledge problem. Complexity must be distinguished from complicatedness. A system that can be objectively described and explained does not necessarily have to be comprehensible for an individual if he or she lacks the knowledge or has a limited view of the system and thus lacks the overview to understand it (Rohpohl, 2009). In this way, what is actually only a complicated system becomes a complex system for the individual with his or her specific point of view. If a system is complex from a subjective point of view, it is therefore an information problem; if it is objectively complex, it is a knowledge problem.

For a detailed description of complexity or the causes of complexity, Reiß (2020) compares the complexity dimensions of multiplicity, variety, variability and ambiguity with the number of system elements and relations (see Figure 3). Consequently, properties can be derived from this. Structural complexity results from a rather static view of the multiplicity and diversity of elements, through which the variety of a system can be described. Functional complexity results from the consideration of the relationships between system elements, which manifests itself in the degree of connectivity and divergence and is described by connectivity. Both for the consideration at element and relation level, the variability and ambiguity must also be taken into account, which can lead to emergent behaviour. For the analysis of VUCA conditions in the context of agile working, however, it can be well shown that ultimately complexity can give reason for a number of uncertainties that need to be managed. If we look at the complexity dimensions, knowledge problems are associated with them if cause-effect relationships are not known from an objective point of view. Information problems result when subjective complexity is involved.

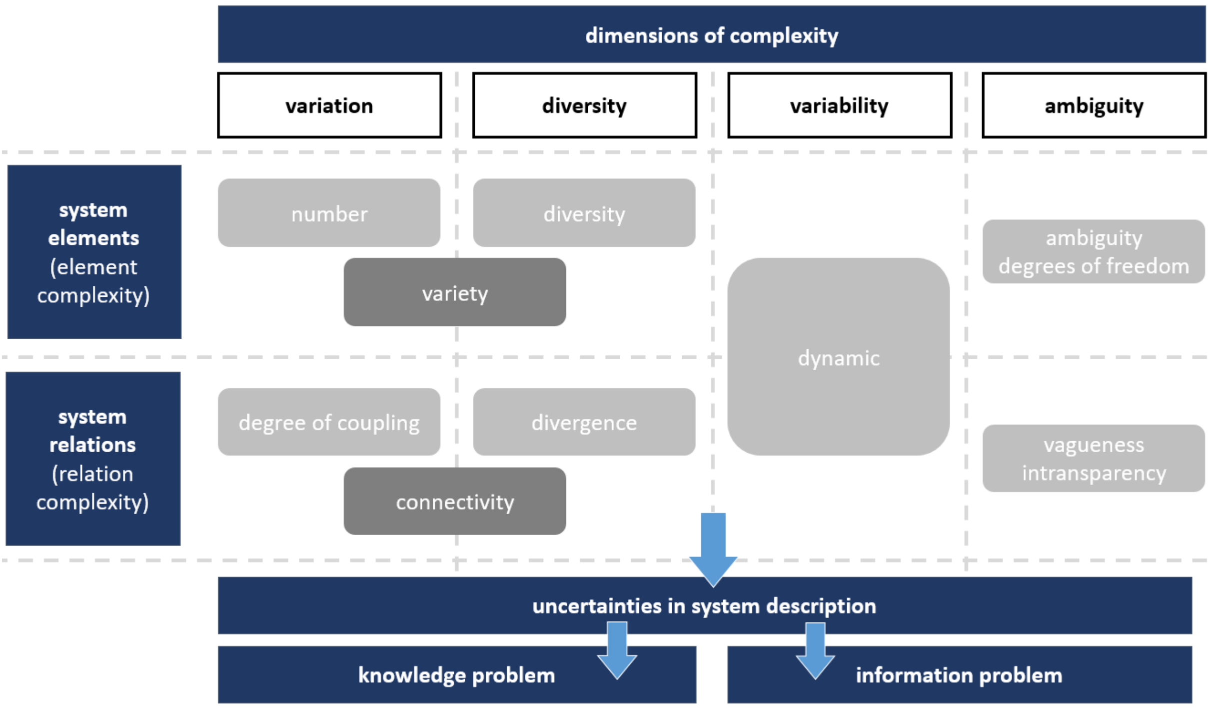

Figure 3: Causes of complexity and their impact

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3.4 Ambiguity

Ambiguities describe situations in which the decision is not based on a clear idea of its effects. Ambiguities are not least due to the fact that cause-effect relationships are difficult to grasp, making threats and opportunities arising from decisions difficult to identify (Waller et al., 2019), because framework conditions change or it is unclear how work results are received in new/changed framework conditions (Bennett and Lemoine, 2014). What the various interpretations of ambiguity in the literature have in common, however, is that these considerations are output-oriented. It is not the situation or the system itself that is perceived as more unstable, but there is uncertainty about how the decision will affect subsequent activities.

The reason for this appears to be, on a macro level, that people fall back on known cause-effect relationships, which, however, are no longer permissible due to changes. Hidden causes behind visible problems are not recognised or are neglected (Bennett and Lemoine, 2014). This is also accompanied by the tendency to linearise cause-effect relationships in order to make the complexity of the decision-making situation manageable (Rohpohl, 2009). Ambiguities are thus associated with a problem of knowledge or understanding.

At the micro level, ambiguity results not least from the imprecise use of terms and the different interpretations of the deposited model concepts (Thunnissen, 2003). This is accompanied by a problem of understanding, which ultimately leads to uncertainties.

3.5 Summary assessment of the analysis of the VUCA factors

The conceptual analysis of volatility, complexity, uncertainty and ambiguity shows that these factors are not equivalent for describing the need to react flexibly and quickly in development and provoke quite different effects for decision-making. The differentiated view not only reveals dependencies between the VUCA factors, but also shows double meanings. In part, effects are explained by themselves. It is striking that both complexity in its facets as well as volatility and ambiguity are more likely to be seen as the cause for the fact that uncertainties occur with regard to the effects of decisions. In addition, volatility and ambiguity appear as a consequence of complexity phenomena in the considered system, which lead to corresponding uncertainties, but which can be described on the basis of the cause-effect relationships (Figure 4).

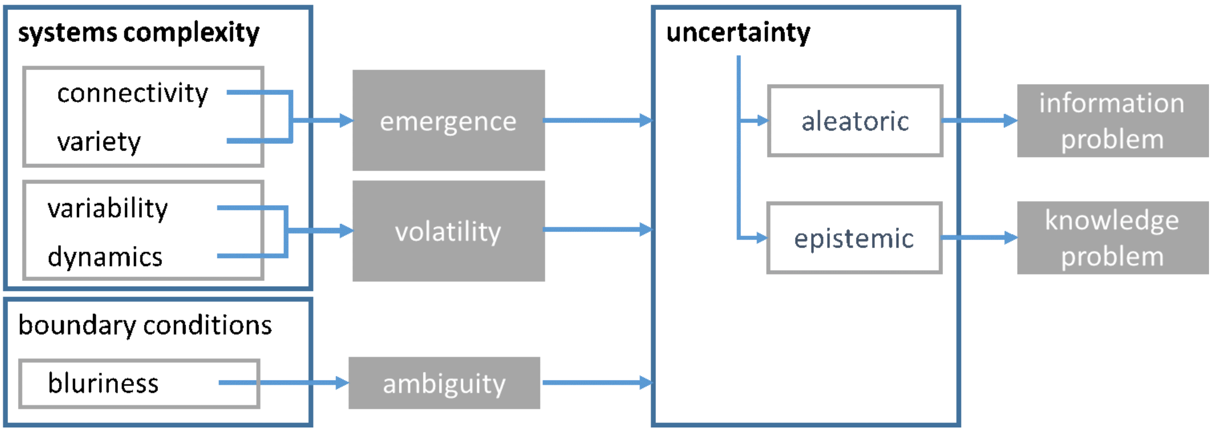

Figure 4: Cause-effect relationships between VUCA factors

While connectivity and variety as characteristics of systems can lead to emergent behaviour if they are not fully understood, variability and dynamics in the system tend to lead to volatility, which can then be treated in terms of aleatory uncertainty if connectivity and variety can be fully described. However, if effects overlap here, meaning that connectivity and variety cannot be fully described and factors of influence from volatility are added, this makes it more difficult to deal with the resulting uncertainties. Ambiguity can also be understood or interpreted as a form of uncertainty, even if it results less from the considered system and more from the context, thus the system environment.

Consequently, two problem areas can be derived from these considerations for product development: Information problems exist when sufficient information and knowledge are actually available to reduce uncertainties, but these cannot be accessed in the decision-making situation. Knowledge problems occur when cause-effect relationships in the system under consideration are not known and

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must first be established. Both problems are certainly addressed by the methods of agile working (Schmidt, 2019), but there is no clear assignment of tools and elements of the method to the problems or the uncertainties addressed by them, so that no clear strategy for action can be derived. In the following, a framework will therefore be presented in order to better place the effects of uncertainty in the development activities or the development processes.

4 FRAMEWORK FOR THE CLASSIFICATION OF UNCERTAINTIES IN DEVELOPMENT ACTIVITIES

4.1 Basic assumptions about the development process

Agile methods primarily support project management as a task of technical management (Paetzold, 2017), which are necessary to compensate for effects of the division of labour and to reunite work results of development. The division of labour in development is not only necessary to deal with the complexity in the development of large mechatronic systems, but also to organise development work effectively and efficiently. The basic assumption for the following considerations is therefore also that the technical knowledge for problem solving is available in the sense of technical-physical development. Agile methods for the development of mechatronic systems should primarily support the data and information flows in such a way that information for decision-making becomes available in the best possible way. Typical tools and elements of agile working also address the developer in particular, who is to be integrated more strongly into these information flows by supporting communication and facilitating coordination (Schmidt et al., 2017). In addition, elements for knowledge building are also offered with the agile methods. Examples of this are the demand for reflection or permanent prototyping. The latter, for example, not only serves the exchange of information, but also helps in exploration.

Figure 5: Process model for development activity

Based on such an approach, the description of development processes should focus on the concrete execution of individual development activities, the basic sequence of which is shown in Figure 5. The actual development task is not only determined by the development phase, but also by the available development knowledge, manifested in models and product artefacts. The development context must also be taken into account, which on the one hand results directly from the project boundary conditions (e.g. available resources, budget) and on the other hand is also influenced by other endogenous and exogenous factors that describe the development environment. To carry out the development activities, information is required as input, which results from the requirements but is also determined by previous development steps. The result of the development activities (output) in turn determines the next steps and their specific characteristics in the development process.

4.2 Allocation of uncertainty factors

As the explanations in chapter 3 have shown, not only causes of uncertainties become quite diverse, but also their effects on decision-making in development. Agile methods with their effect mechanisms promise to build capabilities to deal with these. However, the diversity presented for causes of uncertainty and cause-effect relationships requires adapted strategies. VUCA influencing factors can therefore be reflected in development activities, as shown in Figure 6.

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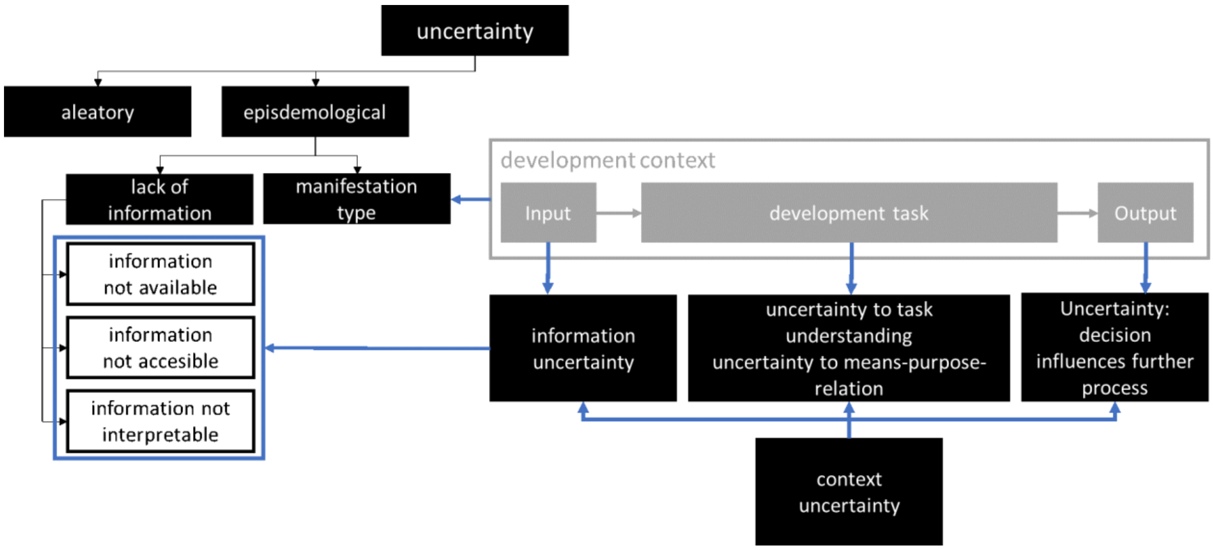

Figure 6: Localisation of uncertainties in the development activities

The basis for the assignment of uncertainties to development activities is the differentiation between aleatory and epistemic uncertainties. First, epistemic uncertainties should be considered, which ultimately point to a knowledge problem, but manifest themselves in missing information, because information is either not available, cannot be interpreted or simply does not exist. Last but not least, it is also important to consider different types of appearances, which means that the information deficit does not always have to be recognisable (De Weck et al., 2007). The input into activities is burdened by uncertainties, which are related to the requirements on the one hand.

Since these describe a target system that does not exist yet, information may simply be missing here. By making assumptions or defining solutions that have to be tested in the course of development, developers use mechanisms of iterative work to build up information. On the other hand, such uncertainties can also arise because information from other development teams is necessary, for which, however, the awareness is not available. Appropriate communication mechanisms can be used to solve this problem.

Uncertainties in task management itself result on the one hand from a different understanding of the task or problem in the development team. This is accompanied by uncertainties in the evaluation of which methods are necessary or suitable to find a solution.

Uncertainties in the output are on the one hand due to the fact that in the execution of the development activities, depending on their interpretation, the result quality itself can fluctuate. Uncertainties result from the choice of solution principles, since additional product-concretising parameters can arise from this, whose significance for processing other development activities is not known. In summary, it can be stated that the results of development activities influence decisions on the further development process, whereupon statements on the suitability and quality of the results have a high significance for the whole system. In addition, development results also harbour a certain ambiguity, since the results are associated with effects on subsequent development processes that are difficult to predict and can represent both opportunities and threats. Last but not least, uncertainties from the development context must also be taken into account. Endogenous and exogenous factors can change the scope for action and decision-making in such a way that the execution of development activities can be questioned, and their input or output can prove to be no longer adequate for the development task.

In the context of development activities, however, aleatory uncertainties that can be related to the variation or fluctuations of influencing variables appear to be detectable and treatable with known methods from the engineering sciences such as simulations, tests or sensitivity analyses. The main challenge here is when such fluctuations occur in complex effect structures. These must then be completely described in order to be able to propagate the effects of fluctuations in the system and deal with consequences. In this case, other methods are required to grasp the consequences of the fluctuations. On the other hand, these uncertainties then often take on an epistemic character, since information or knowledge about the interrelationships is lacking.

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5 DISCUSSION OF THE FINDINGS

For the treatment or consideration of epistemic uncertainties in particular, agile methods certainly provide promising and useful tools. However, it becomes apparent, especially in practical application, that if they are not used correctly or are misinterpreted, their benefits are lost (Michalides et al., 2022). Ultimately, epistemic uncertainties in particular are linked to information and knowledge problems for which solutions can only be found if they are considered in the specific context of the development organisation, since the data and information in development are related to them. However, this also makes it necessary to question the tools and elements of agile working according to what contribution they can deliver to solve this information but also knowledge problems. This requires a deep understanding of the interdependencies in the support of information flows through agile working.
The framework presented in this article is intended to serve as a basis for further in-depth investigations. For this purpose, it is necessary to structure the influencing factors and mechanisms of action identified in Chapter 3 more clearly and to reflect them in a more differentiated way in the development process. Consequently, clusters of uncertainties need to be identified for which suitable mechanisms of action can then be sought to deal with them. The aim is not to avoid or reduce the uncertainties, but to allow them and to deal with them in such a way that the resulting opportunities can be used.

6 SUMMARY AND OUTLOOK

The term VUCA is often used to describe dynamics and changeability. However, the generic use of the term in the context of changeability is not based on a differentiated description of the factors. This sometimes leads to inconsistent use, since, when used without clear differentiation, the meanings of the VUCA term and the associated factors sometimes overlap or even mix.
This paper clearly differentiates the factors of the VUCA term, describes the cause-effect relationships between them and locates these uncertainties in development activities in the context of agile product development. On the basis of this work and the model set up, the cause-effect relationships can now be operationalised and, building on this, further research can be initiated in a more targeted manner. The results form the basis for further qualitative research with expert interviews and workshops. This makes it possible to concretise the interdependencies and to prepare these findings as a basis for action strategies in dealing with them.

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