2 The Omnipresence of Complexity

Today the term complexity suffers from inflationary use, having become a buzzword that is applied without really knowing about its specific meaning. Following the news makes it seem like "complexity increases" in almost all areas and "complexity is the most important challenge" of the future. Sometimes, descriptions of "complexities" appear. Apparently, the plural gets applied in the absence of a comparative degree and not to express the occurrence of different types of complexity. The term complexities gets used for overbidding "normal complexity". When asking the authors of such statements for a definition of the fundamental challenges, this often remains unclear.

Declaring a problem as being complex is often based on insufficient knowledge about the situation. Or in other words: If one characterizes a situation or question as complex, he often means that the original cause of an undesired effect is not transparent—and therefore cannot be treated.

Methods provide procedures and support systematic problem-solving. Numerous methods have been designed for managing complexity—focusing on different complexity origins, interacting with different types of system elements and pursuing different objectives. Just declaring a question as complex and selecting a method is not enough. The selection of a method requires knowledge about the complex problem and certainty about the desired objective. The dilemma is that if a "complex" problem means that it is not understood (not transparent), it is hardly possible to determine a specific objective. Thus, the acknowledgement of complexity cannot directly be followed up by selecting a method for its treatment, but requires measures for creating a better understanding first. When selecting and successfully applying a method, one must ensure that the purpose of the method fits the problem at hand. Systematic complexity management initially identifies underlying causes for the undesired effects called complexity, specifies the type of complexity and then determines suitable strategies and methods to be applied for solving the challenge.

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The following sections of this chapter briefly introduce the basics of complexity as an important engineering challenge, depict the structure and specify the target group of the thesis.

2.1 About the Basic Complexity Survival Skills for Engineers

As omnipresent as the existence (or at least the assumption) of complexity is, the strategies, methods and tools offered for its management are equally numerous. A somewhat radical strategy gained significant traction in the popular book market: Simplify Your Life has become a bestseller promoting the notion of overcoming everyday complexity by avoiding or even ignoring it [1]. While some of those approaches may work for managing an overloaded personal calendar, professional work problems like a complex production process flow should—obviously—not be managed by ignoring its existence.

Strategies of complexity management aim at curing the origins of complexity or help to mitigate its impacts. For example, Schuh and Schwenk laid out a straightforward procedure for handling the excessive creation of product variants [2]. If excessively numerous product variants represent the negative impact of complexity, tackling the creation of new variants focuses on the root cause. Baldwin and Clark describe how architectural component interdependencies can be controlled and optimized in order to minimize the product or product portfolio complexity in a modular or integral product structure [3]. If the effect of complexity is an unmanageable impact between interconnected components, then such an approach with reduced interfaces tackles the cause.

These two examples of counteracting complexity depict the major challenge: How do we determine the right method of complexity management if the origin of this complexity is not obvious? The methods of variant management mentioned before, as introduced by Schuh and Schwenk, can be very powerful—but not in the specific case if the complexity is emerging from the unmanageably large number of component interconnections within a single product.

So even if an engineer knows several approaches to handle complexity, selecting one without profound understanding of the problem is like grabbing an arbitrary tool from a toolbox only knowing that the car makes “some strange noise”—nobody would treat a problem this way. And if an engineer only knows about one approach towards complexity management, it could be a risk that once he is facing complexity in his daily work this becomes the tool of choice. Of course, such a narrowly focused procedure is doomed to fail eventually, as different situations, objectives and boundary conditions require different methodical approaches.

Thus, complexity often implies a lack of understanding in the problem domain, incomplete information and uncertainty. If the problem were understood and all required information were available, then the associated system could be modeled and various solution approaches be applied. This narrows down the challenge of complexity management: If confronted with a complex problem, we first need to understand about the origin of complexity before we can purposefully decide on a strategy of management.

As stated in the title of this chapter, complexity is omnipresent and we deal with it every day. It is not something new or extraordinary. Just the impressive amount of sensory input humans continuously receive from their different senses presents a complex challenge to manage—and we manage it—continually. However, managing the complexity emerging from artificial, technical systems seems to be a poor fit with our innate complexity management abilities. While humans are easily able to pick out relevant information from thousands of simultaneous and competing visual impressions, the same humans cannot reliably comprehend a network of processes containing a couple dozen elements. Educational management games based on system dynamics are often applied to illustrate how easily even experienced managers can destabilize (hypothetical) supply chains or entire enterprises [4, 5].

As the human ability to control natural complexity cannot be applied to technical challenges and the wide variety of technical complexity asks for specifically appropriate approaches, a sound understanding of complexity, its characteristics and specifications is essentially required. This is then the basis for investigating appropriate procedures and methods to guide and support engineers in solving unavoidable complex challenges.

Not only is (a specific kind of) complexity management a natural ability of humans, complexity management for non-natural systems has a surprisingly long history. More than 2000 years ago, Greek philosophers began tackling societal and governmental challenges, which were characterized by significant complexity. And from these times on, systems and their inherent complexity became described, analyzed and managed with many approaches—based and embedded into the specific time. It is an important insight that complexity and its management are not challenges of recent times only. However, one could get this false impression, as in the last few years complexity gets heavily used for explaining problems. In fact, complexity is often used as an excuse, such as when projects miss their objectives and when major accidents happen. But the historical development shows that complexity and its management underwent a long-lasting evolution—and every epoch had to tackle its complexity using the means available at the time.

Today, interacting with complexity is crucial in many fields, and also almost everywhere in engineering. For various reasons, knowledge about procedures, methods and tools are not equally distributed among the different engineering disciplines. These disciplines were founded at different times—e.g. software engineering emerged later than product development—and have different states of the art and use different resources. Understanding the links and commonalities between the disciplines can support a sound basis for identifying opportunities to transfer knowledge concerning complexity management.

This thesis shall contribute to gaining a better understanding of the phenomena aggregated in the term "complexity" in an engineering context. This understanding shall be reached by classifying complexity by relevant criteria, differentiating between complicated and complex challenges, investigating useful definitions of complexity and characterizing the impact resulting from complexity. In addition, well-established complexity management approaches like variant management, interface management and Pareto analysis are introduced, and their range of application and methodic background are described.

As the sole discovery of complexity does not clarify its origins in a system, this thesis shall further provide insight into where complexity emerges from in the engineering field. Knowing the root causes of observed complexity and being able to specify this complexity, these represent the basis for selecting appropriate methods and tools. For such applications, the thesis introduces a generic framework.

2.2 Who Should Read This Thesis?

The content of this thesis is partly based on the lecture “Complexity Management for industrial applications” (German: Komplexitätsmanagement für die industrielle Praxis), which the author held from 2009 to 2014 at the Technical University of Munich, Germany (Master’s program in Mechanical Engineering) and content originating from business trainings the author conducted for several years with numerous companies.

Furthermore, findings from several academic research projects in the field of structural complexity management and knowledge management, which the author conducted from 2008 to 2014, have been integrated. And industrial insights gained from more than 20 consultancy projects and development of complexity management software over a period of 7 years also contribute to the basis for this thesis.

This thesis is aimed to be a supplemental source for students of engineering disciplines, who became aware of specific challenges of complexity and want to get a more general insight into the topic. Instead of teaching a single or some specific methods, this thesis should provide a big picture of complexity management, guiding students through the necessities, ideas, concepts and implementations. The thesis is meant to prevent an isolated view on complexity, either that complexity is harmful and should avoided at all means or that there is “the one solution” to manage complexity. Thus, this thesis should mediate an awareness of complexity as a natural, unavoidable characteristic that is necessary to control and manage.

This thesis is also meant to serve engineers in practice as a guide towards successful complexity management. It shall show engineers how to make complex issues transparent and enable them to identify the right methods and tools for their specific complexity challenges. By explaining the term complexity, its origins, history and the established methods to tackle it, the thesis gives engineers a framework at hand for identifying needs and possibilities in dealing with complexity as it appears in their day-to-day projects.

2.3 Structure of the Thesis

The thesis is partitioned into four main chapters numbered 3–6, which introduce the occurrence of complexity in engineering, the historical background of complexity management, a classification of approaches towards handling complexity in engineering disciplines and a framework for application.

Chapter 3 focuses on providing an understanding of the phenomena of complexity in engineering, distinguishing complexity from other challenges and providing an overview of common definitions. After introducing the challenge of complexity, the commonly applied approaches of their management in engineering are introduced.

Chapter 4 describes the historical background of complexity management, highlighting the important epochs, their key actors and their discoveries, findings and developments. From the appearance of early system awareness in ancient Greece, described by Aristotle in his Metaphysics, to the seventeenth century with the creation of mechanical philosophy and the discovery of classic physics and to modern system sciences and management approaches, this chapter follows the thread of an ongoing development spanning over two millennia. The historic background shows that modern complexity management does not represent revolutionary approaches for new challenges, but is based on an evolutionary process that is always driven by the needs of each specific time period.

After the reflections on the historical evolution, Chap. 5 provides a classification of complexity management by core engineering disciplines. It is often useful to transfer knowledge and methods between domains and integrate them in a new context. And while some engineering domains make extensive use of complexity management, others do not—e.g. for reasons of tradition, lack of transfer effort or differences in applied vocabulary. But when engineering domains undergo significant change, for example as we have seen in software engineering in the last decades, demand for complexity management can change too—and new methods for dealing with complexity can become important. The classification in Chap. 5 shows exemplary research work, findings and applied management approaches in identified engineering core domains, indicates their mutual overlaps in terms of similar approaches and fills in blank spots to yield a comprehensive map.

Chapter 6 builds on the knowledge mediated in the previous chapters and introduces a generic complexity management framework. This is based on structural management approaches, which have been successfully applied to complexity challenges recently. Each step of this framework is described in detail, with a specific focus on the challenge of information acquisition. The successful execution of this task is of major importance for all approaches of complexity management and presents specific hurdles. The hurdles are indicated in Chap. 6, as well as approaches to cope with them.

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