Chapter 18
A Business Typological Framework for the Management of Product Complexity

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18.1 Introduction

Managing product variety in the stage of order acquisition as well as in product development and manufacturing is a key factor to a company's success [1]. Technical products are becoming more complicated and so the demands for product documentation. On the other hand, new requirements for flexibility in product development and manufacturing arise due to deregulated and global competition and the trend of product customization, which Bliss characterizes as new market dynamics [2]. Thereby, it is generally accepted that the customer's desired and perceived diversity as well as the desired individuality of products has to be dealt with a minimum of organizational efforts.

Commonly, the term complexity is used synonymously for product variety in this context. A generally accepted definition for complexity is yet not at hand, but most approaches include organizational effects and take into account that high variety leads to problems and uncertainties in forecasting demands and control of manufacturing and operations. Furthermore, complexity is considered to be strongly company specific.

In the present chapter, we present a business typological framework for management of complexity. Key element is the Hannover House of Complexity, which defines the effects of certain complexity management tools and methods on distinct complexity measures on the one hand. On the other hand, the interdependencies of these tools are documented.

Related to the business model of mass customization product, configuration systems are exemplarily discussed and classified in the Hannover House of Complexity.

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18.1.1 Motivation

According to the process-related management methodologies such as quality management, configuration management, and risk or environmental management we are developing an integrated approach for complexity management. It is not our aim to develop a general theory of complexity, but a scientifically well-grounded process model, which is applicable and implementable in engineering science and mainly focuses on product development. Our work is based on three basic assumptions:

1. A certain amount of complexity is beneficial in today's market environment.
2. There exists an ideal complexity—an increase will not lead to higher revenues.
3. Ideal complexity and complexity management are depending on business type and marketing strategy.

By means of business typologies, models are developed for the assessment of complexity management methods and tools according to a company's specific requirements. A main focus is the formulation of standard sets of methods and tools for different business types and marketing strategies such as business to business (B2B) or business to consumer (B2C). We focus on the product development process since product development is the central transfer site for information in a company [3].

18.1.2 Structure of the Chapter

Section 18.2 provides the theoretical background of complexity and complexity management. As framework the Hannover House of Complexity is presented in Sect. 18.3. In Sect. 18.4 the product-process change matrix is characterized as business typology with focus on the business model of mass customization. Section 18.5 then introduces product configuration systems in context of knowledge-based systems and classifies them into the Hannover House of Complexity. Closing the chapter, Sect. 18.6 contains the conclusion and drafts further research questions.

18.2 Complexity and Complexity Management

Cybernetics and system theory can be identified as origin of complexity theory [4]. These approaches have already been adapted to and further developed for various scientific disciplines such as, e.g., natural science and social and labor science [5]. The analysis of these shows that general definitions or modeling principles do not exist. Instead, complexity is mapped and reduced on the particular problem statement.

Generally accepted is the fact that complex systems can be represented at least in the dimensions of diversity, variety, and dynamics. Nevertheless, in the most approaches, dynamics can also be translated into diversity since it is the count of different system states and change possibilities [6].

Approaches in engineering science are also founded on cybernetics and broken down to complexity of products as well as development and production processes. With respect to mechanical engineering, external and internal product complexity is differentiated. External product complexity is understood as diversity of a company's offering, which is perceived and stipulated by the customer. In contrast, internal product complexity is defined as the number of subassemblies and components as well as their design and combination rules in order to assemble them to end products [7].

A lot of authors emphasize that product complexity and process complexity are strongly intertwined. Multivariant products thus lead to an increase of complexity in all operational structures and processes since the high quantity of end products, alternatives, components, and the corresponding documents for each project and each customer has to be managed in operations and the whole supply chain [8].

From our point of view, a system can be considered as complex when it is composed by a large number of components which are arbitrarily linked together. The system can have different states over time, but the system's behavior is diffuse since it cannot be simulated or fully predicted. The system elements are not limited to the use in one single system but can also be used in different systems in the sense of commonality.

18.2.1 Complexity Management

According to Schuh, the management of complexity is "the design, development and control of business activities regarding products, processes and resources. By managing complexity it is aimed to dominate diversity along the whole value chain so that customer satisfaction as well as organizational efficiency gets maximal" [9].

Generally, different aspects of complexity management and single tools can be found in literature. Bliss concludes that the major process management schools of the 1990s can also be regarded as complexity management methods. So lean management is an answer to increased complexity of the production program and the manufacturing techniques, whereas business process reengineering focuses on organizational complexity. Variant management as the third method concentrates efforts of product complexity and customer complexity. Here, e.g., modularization is a valuable building block. Nevertheless, an integrated model for complexity management is still not at hand [2].

From our point of view, this argumentation leads to three basic views of complexity management:

- Management of product complexity: Measures in different areas of the company, which purpose is designing and controlling the complexity of end products as well as their components and individual parts depending on their functional and design requirements
- Management of resource complexity: Methods in order to design and control the complexity of production resources, raw materials as well as knowledge and personnel in the value chain
- Management of process complexity: Approaches which aim at design and control of complexity of operational and organizational structures

As basic strategies for complexity management a literature review shows three basic approaches. On the one hand, different authors name reduction of complexity as the first basic goal. This strategy aims at streamlining the existing product and process portfolio for a short-term complexity reduction. Here, product variants with low demand and overlaps in the overall offering have to be identified and eliminated.

The second step is complexity control which means dealing with strategic planning and development of necessary complexity. Here, approaches for product family design, modular design kits and solution space modeling in general are subsumed. Additionally, an according setup of the manufacturing organization and of order processing has to be implemented.

The third approach is prevention of complexity where new further product and process variants have to be assessed regarding additional benefits for company and customer before realization and implementation.

18.2.2 Measuring Complexity

The lack of a common definition of complexity is continued in measuring it. But as prerequisite for managing complexity, it is necessary to determine an ideal amount of complexity or to differentiate between good and bad complexity. The early attempts of finding describing dimensions failed and resulted in a multitude of measures which could not exactly assess complexity [10].

After a wide-ranging literature review, Bandte condenses different complexity management approaches of various scientific areas and derives properties of complex systems such as variety and diversity, dynamics, feedback from the environment, nonlinearity, self-organization, limited rationality, and emergence to name only a few [5].

For his complexity management approach, Schuh uses the so-called complexity drivers which are diversity on the one hand and dynamics on the other hand. His concept of diversity encompasses both the diversity of system elements and the diversity of relations between these elements as well as the variety of system states over time [9].

Gießmann uses a compact approach from point of view of logistics and describes complexity in the dimensions of variety, heterogeneity, diversity and uncertainty. All these dimensions are dependent since, e.g., an increase of dynamics results in an increase of uncertainty because the prediction of future developments and system states is more difficult. So it is not enough to measure a single aspect of complexity or to consider only a limited count of system elements but to examine the whole system and all possible occurrences [11].

Broken down to manufacturing organizations, Frizelle reduces this to even two dimensions by the consideration that complexity arises out of the presence of variety since increasing variety generates uncertainty so that the system's behavior cannot be completely predicted. According to him "variety can be seen in terms of trajectories—the path a system traces over time; the greater the variety, the more trajectories are open to the system. Uncertainty comes from not knowing which trajectory the system will follow" [10].

Focused on product development, the consideration of commonalities of components between different systems is a relatively new measure. This is important at designing modular design kits since modules should not only be restricted for use in only one system in order to use economies of scale. Hence, a change to a component is more critical when different configurations and end-product variants have to be checked and taken into account. In our first approach, the dimension of nonlocality (later trans-connectivity) was ought to reflect this. Other dimensions in this approach are variety and heterogeneity of components, dynamics in the sense of likelihood of change over time, and uncertainty of system states and system development [6].

Since the measures mentioned above are not fully independent the approach can be simplified from point of view of the possible solution space a product can be developed from (Fig. 18.1).

Hence, one dimension for product complexity is the size of the possible solution space with respect to diversity and the predictability of the boundaries of the solution space regarding uncertainty. The second measure is the predetermination of the

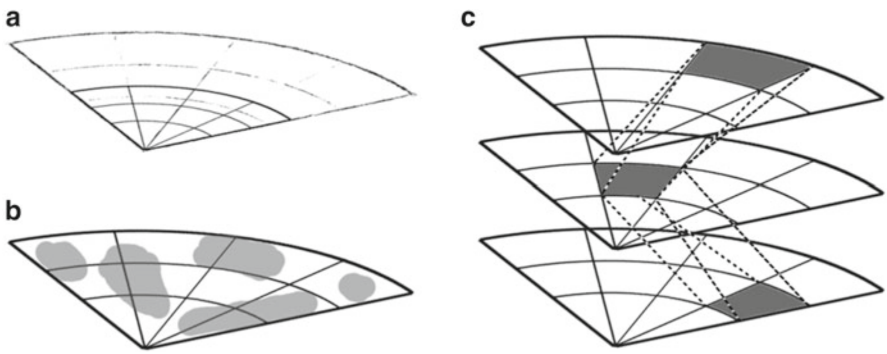

Fig. 18.1 Complexity measures of a solution space for product development: (**a**) size and determination of the solution space, (**b**) degree of exploration of the solution space, and (**c**) interaction between multiple solution spaces

solution space itself. Regarding diversity, we define the degree of exploration as dimension which means that either all possible solutions are calculated and documented beforehand or only part of them. The latter leads to higher uncertainty, since the validity of all end-product variants is not checked. So, possible conflicts are not completely foreseeable. As the third dimension, the commonality of components between different solution spaces is introduced. The more solution spaces are addressed, the more complicated is the prediction of the effects when components change.

Note that at this point we only focus on the possible solution space in product development. The interactions between this type of product complexity and other occurrences of complexity, e.g., requirement complexity or manufacturing complexity, are beyond the scope of this chapter.

18.3 Hannover House of Complexity

The Hannover House of Complexity has to be understood as framework in which different methods, tools, etc. are classified with regard to their effect on distinct complexity dimensions. The basic concept of the House of Complexity is depicted in Fig. 18.2. In principle, the design is similar to the house of quality known from quality function deployment.

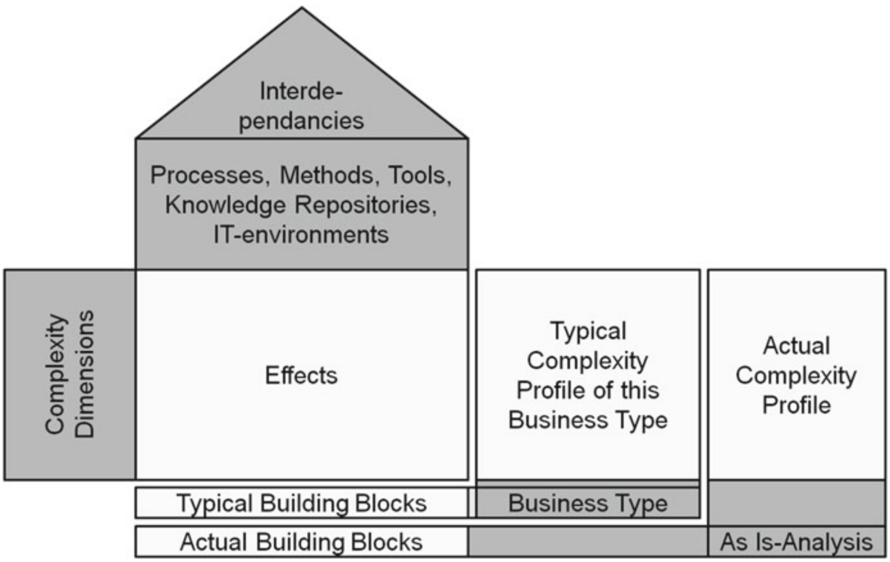

Fig. 18.2 The Hannover House of Complexity—architecture

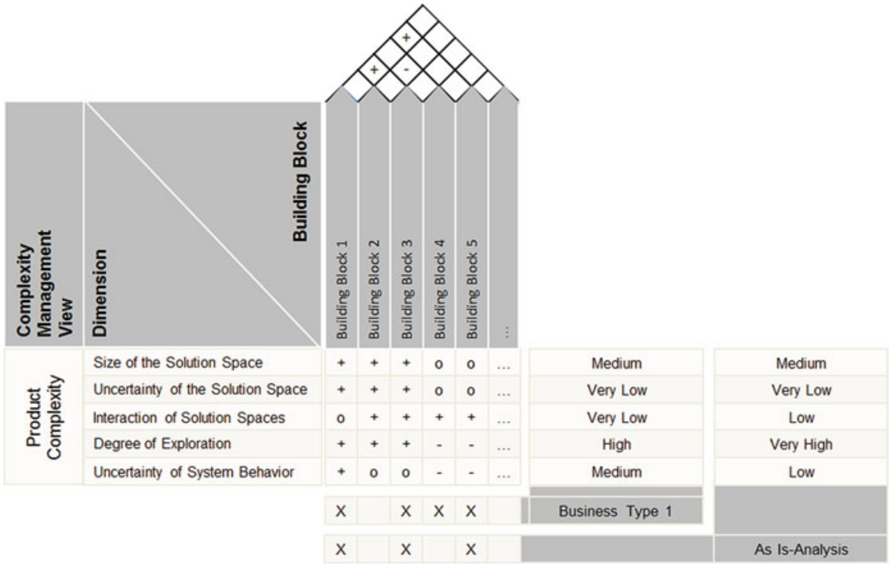

Fig. 18.3 The Hannover House of Complexity—framework

In opposite to QFD, the major areas are not the mapping of customer requirements to functions or properties of the product but the mapping of different building blocks for complexity management and their particular effects on different complexity dimensions. The roof of the House of Complexity documents the interdependencies of these building blocks to estimate whether two of these building blocks intensify the benefit of or, on the contrary, extenuate each other. Since the framework is set up as aid for decision making, a reference to a standard company of an according business type is given for comparison. This includes the choice of typical building blocks on the one hand. On the other hand, it also allows the assessment of the complexity profile which can be seen as usual at this particular business type. The architecture of the House of Complexity is completed by the fields for the as-is analysis. An example of the detailed framework is given in Fig. 18.3.

In the example above, the effect of different building blocks for complexity management on the dimensions of product complexity is shown. Based on a business typology, a company assigns itself to a business type 1. Comparing both complexity profiles, it can be seen that in contrast to the benchmark, the interaction of solution spaces, the degree of exploration of these solution spaces, and the overall uncertainty of the system's behavior differ. This is due to the missing of a complexity management building block which is yet not implemented at the company. Furthermore in the roof the mutual effects of building blocks one to five are depicted.

As can be seen from this example it is not the aim of minimizing every complexity dimension. In the example above, the uncertainty of the systems behavior increases.

18.4 Business Typology: The Product-Process Change Matrix

The product-process change matrix was introduced by Boynton et al. in 1993 and can be understood business typology (Fig. 18.4). The two dimensions for differentiating the single business types are product change and process change. The first focuses on the demand for new products and services; the latter addresses all procedures and technologies to develop, market and manufacture them [12].

Both types of change can either be stable, which means slow and foreseeable, or dynamic in the sense of fast, revolutionary, and generally unpredictable. Within the fields of the matrix, the four basic business models invention, mass production, continuous improvement, and mass customization are differentiated.

Invention refers to organic or job-shop design, where permanently new products and the according processes for development and production are invented which have to compete in market through differentiation and innovation. After the product developed to a certain degree of maturity and market transformed to mass market, the business type changes to mass production. Here the manufacturing processes have to be kept stable in order to achieve economies of scale. Boynton et al. point out that there exists a critical synergy between invention and mass production since the mass production model is incapable of developing completely new products and the invention model has to deliver new products and processes to the mass producer.

The third business model is named continuous improvement and is based upon the improvement of processes and product quality while reducing costs. Known approaches are TQM and kaizen [13].

Mass customization is the fourth business model. The idea behind is that customer-specific products can be tailor-made by the use of flexible but stable processes with mass production efficiency. Taking into account that only the customer himself is able to formulate his specific needs and requirements, Piller suggests that "MC refers to a customer co-design process of products and services, which meets the needs of each individual customer with regard to certain product features. All

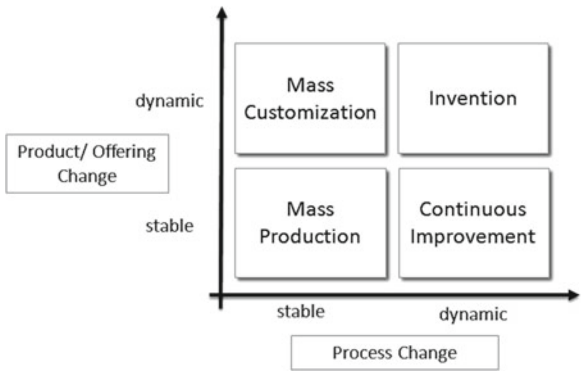

Fig. 18.4 Product-process change matrix acc. to [12]

operations are performed within a fixed solution space, characterized by stable but still flexible and responsive processes” [14].

In order to become a mass customizer, a company has to transform its business model along the so-called right path. This means that all business models have to be traversed without skipping any, especially since the transformation from mass production to MC cannot be done without continuous improvement since the mass production processes cannot stand the high change ratio and flexibility of mass-customized goods.

18.5 Application Example: Classifying Product Configurators

In this section we focus on the business type of mass customization and describe the classification of product configuration systems in the House of Complexity. Therefore, we define configuration as a problem-solving task of knowledge-based technologies. Afterwards we present different approaches for sales configuration systems and engineering configurators. Finally, these are classified in the House of Complexity with some auxiliary building blocks for complexity management.

18.5.1 Configuration as Problem-Solving Task

Sabin states that “configuration is a special case of design activity with two key features: The artifact being configured is assembled from instances of a fixed set of well-defined component types and components interact with each other in pre-defined ways” [15]. Since configuration systems are more than just filters applied on the portfolio of capabilities, a knowledge base has to be implemented to define possible combinations of components or restrictions.

18.5.2 Sales Configurators

When considered as sales support, the main tasks of a sales configuration system are providing a technically complete and correct product specification, commercial quotation costing, automatic generation of quote documents, and visualization. Another capability of current sales configurators is data collection since the system is able to store all information according to the configuration process, i.e., the time for each configuration step, configuration history, or abort of configurations. Hence, these systems can complement activities of marketing regarding trend scouting and preference analysis [13].

One of the most important characteristics is a sales configurator's ability to translate customer requirements into a valid product specification. On the one hand, these plausibility checks assure a working end product for the customer. On the other hand, decision support is realized. Nevertheless, if the manifold of configuration items is too big, the customer might not be able to choose the right components, which is expressed by the concept of mass confusion [13].

Choice navigation systems add a bidirectional communication component to an online sales process. In contrast to the sales configurator, a choice navigator is able to guide a customer to a certain popular solution [16]. On the basis of detailed customer information, a recommended default configuration is presented which then can be modified by the user. The idea behind is to use statistical data or data from social networks to forecast customer preferences or take influence on the customer in the sense that "other people who define themselves as stylish or sportive have chosen this or that product." The inference mechanisms of such systems rely on case-based reasoning so that the system permanently learns about other configurations [15]. First experiences with those systems are made in automotive or clothing industry. Nevertheless, research in this context is still in the beginning.

18.5.3 Engineering/Design Configurators

While sales configurators aim at managing external product complexity, engineering configurators focus on the internal complexity. Here, engineering configuration has to be considered as knowledge-based engineering (KBE) approach for transforming a design problem into a configuration problem, e.g., by implementation of dimensioning or calculation formula, design rules or manufacturing restrictions.

This implies that all necessary engineering knowledge has to be formulated in a domain-specific knowledge base, which extends the geometric product model. New configurations are calculated and processed by an inference engine where basically the following paradigms can be distinguished [15, 17]:

- *Rule-based reasoning*: The knowledge representation relies to design rules, which are formulated as IF-THEN-ELSE statements. Rules are fired procedurally and can be used to execute subordinate rules or delete them temporarily from the working memory.
- *Model-based reasoning*: The limitation of the possible solution space is done based upon a physical and/or logical model (constraint based) or by representation of resource consumption and allocation (resource based).
- *Case-based reasoning*: In this approach, the knowledge representation is not explicitly modeled in form of rules or constraints. The knowledge necessary for reasoning is stored in cases that represent former configurations. Depending on the degree of maturity of the inference engine, either the system is limited to search for existing solutions, which match exactly to a given requirement profile, or the system is able to assort a set of existing cases, which represent the best fit.

Highly developed case-based systems are able of mixing or altering exiting cases in order to adapt them to new situations.

18.5.4 Complexity Management Using Configurators

In the following, some of the configuration systems mentioned above are exemplarily classified and discussed in the House of Complexity (Fig. 18.5). Therefore, modular product architectures and the specification technique of degrees of freedom of shape attributes [18] are added. A detailed examination of all interdependencies and effects on the complexity dimensions is beyond the scope of this chapter and still part of our actual research. For better readability, the area for the as-is analysis has been left away in the picture below.

As can be seen in Fig. 18.5, we estimate that rule-based configuration systems either for sales or engineering usually do not affect the possible solution space for product development. The rule concept is adequate for documentation of an existing solution space since all configurations have to be predetermined as well as all restrictions, which decreases uncertainty and sets the degree of exploration to 100 %. The uncertainty of the system's behavior with respect to the end product

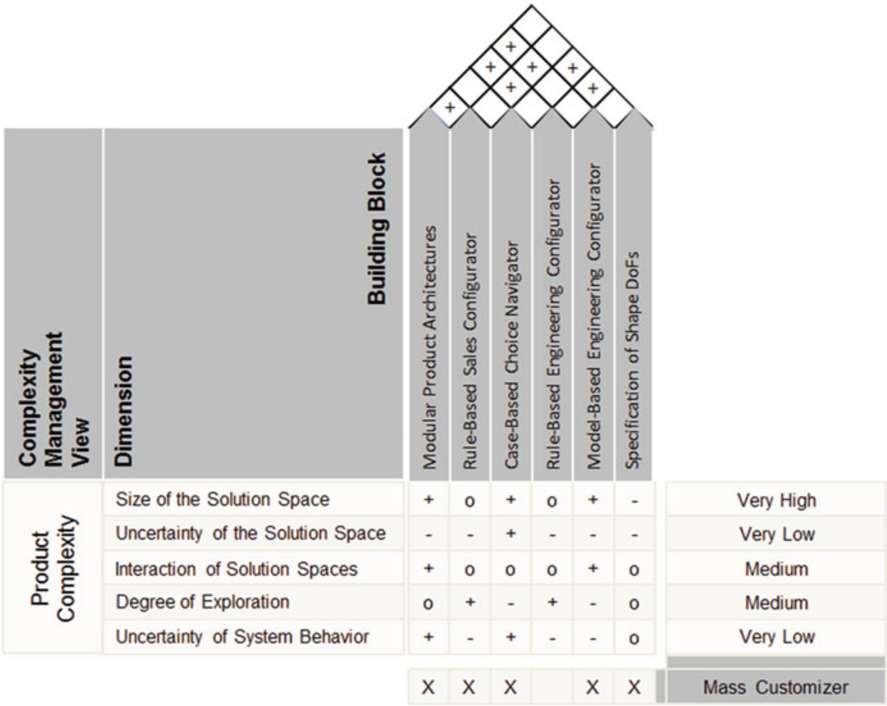

Fig. 18.5 Configuration systems and auxiliary tools in the House of Complexity

vanishes. Since rule-based engineering configurators are too inflexible for efficient use in mass customization, this is not considered as typical building block for complexity management here.

Model-based configurators have different effects. Here, the size of the solution space is usually enlarged but also reducing uncertainty since the end product is represented by a stable model. The degree of exploration of the solution space decreases since not every possible end-product variant has to be planned beforehand. When coupled with modular product architectures, the effects of the configuration systems will be amplified.

On the other hand, certain specification techniques can limit the possible solution space by predefining or limiting change possibilities and thus restricting product variants.

18.6 Conclusion

In the present chapter, we introduced various complexity management dimensions and measures and set up the Hannover House of Complexity Management as a framework for managing complexity. In the application example, we classified different configuration systems in the House of Complexity.

Further research points on the implementation of other complexity occurrences. Already mentioned was requirement complexity, which basically leads to the solution spaces we have discussed for product development. Another extension is manufacturing complexity which also has to be according to the possible solution space.

As second research question, the operationalization of the complexity dimensions is currently investigated. Until now we can identify whether a particular dimension can be either high or low which can be in case subjective. Real and transparent calculating complexity would grade this approach up and simplify decision making.

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