THE "IDEAL" USER INNOVATION TOOLKIT - BENCHMARKING AND CONCEPT DEVELOPMENT

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Abstract

User innovation toolkits offer many benefits, for example the efficient access to customer needs, the realisation of individual products and reduced development risks. While these toolkits are spread in many industries, they are not very common for mechanical or mechatronic products. To improve the applicability of these toolkits, our paper develops a general concept of an "ideal" user innovation toolkit. It examines existing applications in a benchmark analysis, develops seven dimensions to categorize user innovation toolkits and identifies best practices. Based on these findings the general concept is derived. It provides support in the early phase of user innovation toolkit design and helps companies to find suitable trade-offs and to develop a tailored solution for their purposes. By that our paper contributes to a better applicability of the user innovation approach.

Keywords: User innovation, User innovation toolkits, Open Innovation, Participatory design

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1 INTRODUCTION

In the last decades the focus of value creation in companies slowly shifted and in the meanwhile directly addresses the customer. Additionally, the demographic change led to a change in values. Instead of materialism, the ideology in developed countries shifted towards post-materialism and self-actualization became one of the most important values. These trends result in more diversified and individual needs and the heterogeneity of the markets grows (Piller, 2006).
Manufacturers meet these conditions with an increased number of variants and market segments. Thus, the identification of each customer's individual needs is both, an essential and a difficult task (Piller, 2006; Hippel and Katz, 2002). Literature usually refers to this difficulty by the term "sticky information" (Franke and Hippel, 2003).
The most spread approach to handle this challenges is mass customization. This includes both, hard and soft customization. While hard customization offers a large variance of modules, soft customization for example only allows individual adaptions through the distributers (Piller, 2006). However, manufacturers following these concepts struggle to access the sticky information and all individual needs (Hippel and Katz, 2002).
Traditional approaches identify this information and customer needs by an exhaustive learning process. Based on market surveys or other methods, a product concept is designed, evaluated and tested with the customers. However, integrating the customers into the innovation process has the potential to improve its efficiency and to reduce iterations. Moreover this may improve both: customer perception and satisfaction. Thus, methods of Open Innovation (OI) offer potential to access the sticky information with reduced costs and efforts. The basic idea is to divide the product development into sub tasks and to use external knowledge to solve these smaller development problems (Hippel and Katz, 2002; Franke and Piller, 2004; Piller, 2006).
User innovation toolkits are one OI method to access the information on customer needs. Simultaneously they enable manufacturers to efficiently realize individual products and thus, to better satisfy the heterogeneous user needs (Franke and Piller, 2004). Despite these advantages user innovation toolkits are not yet spread in the field of mechanical or mechatronic products. Only few applications are realized, while for example in the food and clothing industries such toolkits are spread (e.g. Nike, Adidas, Spreadshirt.de, etc.).
This arises a need for further research to improve the applicability of user innovation toolkits. Yet, existing research does not provide sufficient support to develop user innovation toolkits for mechanical or mechatronic products. Therefore this paper develops a general concept for these toolkits based on best practices. The concept sets the foundation for toolkit developments in order to improve their applicability.
In the following we first define our understanding of user innovation toolkits and provide an overview of their features and effects. We then briefly discuss current research in this field and derive our research question. Based on that the methodology of this paper is presented. It mainly consists of a benchmarking analysis and the concept development. We present and discuss the results before the paper concludes by providing an outlook on further research.

2 THE APPROACH OF USER INNOVATION TOOLKITS

2.1 Definitions

Toolkits which integrate the customers in product development occur in various types (Franke and Piller, 2004). According to these authors some toolkits are very complex and offer a large solution space. They mostly require technical knowledge and mainly aim at business-to-business relations. One example is the toolkit for designing individual integrated circuits presented by Hippel and Katz (2002). Another type of toolkits mainly occurs in consumer markets and only offers a small solution space. One example of this type is a toolkit for designing eyeglasses (Franke and Piller, 2004; Hippel, 2001). Therefore Franke and Piller (2004) suggest to rather use the term "toolkits for user innovation and design.
Yet, all these types of toolkits aim at the transfer of development tasks to the user, at profiting from crowdsourcing (Piller and Walcher, 2006) and to minimize risk and cost within development projects (Shah and Franke, 2003).
According to Reichwald and Piller (2006) these toolkits can be distinguished in three categories:

- Toolkits for idea transfer offer a wide solution space, aim to identify innovative ideas and transfer them from users to the company.
- Toolkits for user design provide a predefined solution space and enable the customers to customize their product by selecting desired features.
- Toolkits for user innovation offer a large solution space and aim to generate innovative product features.

Configurators, which for example are widely spread in the automobile industry, can be assigned to the category of toolkits for user design. However, fully individual products with innovative features can only be achieved by user innovation toolkits.

Slightly adapted from Hippel and Katz (2002), we define a user innovation toolkit as the coordinated and integrated set of tools that enable users to develop new product innovations for themselves.

2.2 The role of user innovation toolkits in product design

According to Hippel and Katz (2002), toolkits in general may reduce the sticky information transfer costs. Besides that, other potential benefits of these toolkits are a "(…) faster, better and cheaper (…)" (Hippel, 2001, p. 248) learning by doing process.

Thus, toolkits can contribute to satisfy the need for individual products. This may increase the customers' satisfaction and a may create a higher willingness to pay for these individual products (Franke and Hippel, 2003). Newer research also shows, that toolkits can additionally serve on cognitive level as learning tools, to support the customer during the process of figuring out what he really wants (Franke and Hader, 2013; Hippel, 2001).

The basic idea of user innovation toolkits thus is to transfer need related development tasks to the customers. In the classical design process of individual products, the customer provides his need-related information in a specification. According to this, the manufacturer designs the product or prototype. The customer usually applies this product in his specific environment, identifies flaws and requests a change. This iteration is conducted until the solution satisfies all customer needs (Hippel, 2001; Thomke and Hippel, 2004).

The learning process described above is usually considered a trial-and-error cycle. It consists of the three phases of design, build and test (feedback) (Thomke and Hippel, 2004). To successfully transfer this cycle to the customer, Hippel (2001) emphasizes the importance of user innovation toolkits. They have to provide design tools to help customers iterating the trial-and-error cycle on their own.

However, the development of the toolkit itself is a difficult task and it might be necessary to develop different toolkits for different users. But still the development of a toolkit only is a one-time investment, which will repay (Hippel, 2001).

2.3 User innovation toolkits in application and research

Despite all benefits depicted in the previous section, in 2002 toolkits for user innovation were only applied to few types of industrial products (e.g. integrated circuits (Hippel and Katz, 2002) or shopping centre design (Helminen and Ainoa, 2009)). Since this time, enabling technologies for user innovation toolkits made remarkable progresses: information technologies (cloud computing, computing speed etc.) and flexible manufacturing technologies (3D-printing, laser cutting, etc.).

However, more than a decade later, we do not observe fundamental changes compared to the situation described above. Only few applications of user innovation toolkits for mechanical or mechatronic products are established and the market is dominated by user design toolkits in the form of configurators.

Shifting the focus to research, numerous works on user innovation toolkits have been published. An extensive literature review can be found in Goduscheit and Jørgensen (2013). They characterize research works based on how they fulfil the five basic toolkit elements. These five elements are complete trial-and-error cycles, an appropriate solution space, user friendliness, libraries of modules and automated producibility checks (Hippel, 2001).

Goduscheit and Jørgensen (2013) confirm our observations and identify that most research only applies parts of the user innovation toolkit approach. Their work especially points out the differences between theory and application: The application of the user innovation approach is often closer to customization than the theoretical position.

Newer research (e.g. Jeppesen, 2005; Helminen and Ainoa, 2009; Piller *et al.*, 2010) mainly focuses on either general effects and applications of user innovation toolkits. Others, (e.g. Lindsay *et al.*, 2012; Hermans, 2014) discuss case studies of exemplary user innovation toolkits. Only Kirchmair (2006) develops a generic user innovation toolkit architecture which is tailored to the development of mobile services. General research on the general development of user innovation toolkits and how they should look like, which extends the 5 basic elements of Hippel (2001) is not known to us.
We state that a general concept of a user innovation toolkit, describing its elements and functions is an essential support to improve the applicability of the user innovation theory. Thus we in this paper focus on the question of how a general concept of a user innovation toolkit for mechanical and mechatronic products should look like to improve the applicability of the user innovation approach.

3 METHODOLOGY

The methodology of this paper consists of two main parts. The first part addresses the analysis and benchmarking of existing user innovation toolkits, while the second part aims to develop the general concept of these toolkits. Therefore, we try to identify and generalize best practices of existing and successful commercial and non-commercial toolkits.
To capture the state of the art of toolkit applications and to conduct the benchmark analysis, we selected a total of ten commercial and non-commercial toolkits or toolkit-like applications for user innovation. To compare them with existing configuration systems, we also included one commercial configurator in the benchmarking. Based on the findings of the literature review in the previous chapter (i.e. the five basic elements (Hippel, 2001)) seven dimensions of toolkits are defined. For each dimension we derived a scale based on our observations of toolkits and existing publications. The features of the analysed toolkits are assessed for each dimension. The assessment has been done in a team by two of the authors (one student, one graduated engineer). The results of the assessment were discussed in a round of experts including engineers and economists from the fields of open innovation, development and manufacturing. Even though the assessment has been performed by only two individuals the defined scales ensure reproducibility and the discussion with experts limits the influence of subjectivity.
Moreover, the functions and processes of the toolkits are analysed and modelled in detail. Therefore we used UML-notation. We identified promising solutions based on the assessments made in the benchmarking. The processes of those toolkits are extracted and modelled. We used these models of best practice and synthesized them to a generic concept of user innovation toolkits. The results were discussed with experts from both sides, manufacturers and OI consultants.

3.1 Selection of user innovation toolkits

We selected a sample of ten toolkits based on an online search and discussions with experts from a consulting agency from the field of open innovation. The selection criteria are as follows:

- online toolkit for mechanical or mechatronic products or objects
- degrees of freedom not limited to a selection of predefined configurations

As mentioned before, additionally one configurator is included in the analysis to compare user innovation toolkits with configurators even though it violates the selection criteria above. We selected the configurator of the Opel Adam as it according to the advertisement offers the possibility to design an individual car and it thus pretends to be a user innovation toolkit. The remaining sample of toolkits involves toolkits from different backgrounds. Table 1 provides an overview of their characteristics and a short description of their functions.

Table 1. Overview of the benchmark analysis' sample (status in June 2014)

toolkit	URL	description	functions
Carfrogger	carfrogger.de	car lamination toolkit	design/share 2D-objects check producibility price calculation and ordering
Cuboyo	cuboyo.com	3D-printing library	upload and sell 3D-objects scale and download objects
Formulor	formulor.de	laser cutting and engraving service	upload/design 2D-drafts choose material and colour

			check producibility price calculation and ordering
Jweel	jweel.com	personalized jewellery	design and share 3D-objects check producibility price calculation and ordering
Leopoly	leopoly.com	3D-objects library	design/share 3D-object
Opel Adam Konfigurator	konfigurator.opel-adam.de	car configurator of a car manufacturer	combine shapes and colours of modules two configuration modes price calculation and ordering
Sculpteo	sculpteo.com	3D-printing service	upload/design 3D-objects choose material and colour check producibility price calculation and ordering
Sculptgl	stephaneginier.com	sculpting toolkit	sculpt 3D-objects (incl. import/export)
Thingiverse	thingiverse.com	3D-objects library	upload/share 3D-objects customize and buy 3D-objects
Trinckle	trinckle.com	3D-printing service	upload 3D-objects, choose material/colour manufacturing recommendations check producibility price calculation and ordering

3.2 Definition of dimensions

In the following paragraphs we define the seven dimensions and their values to characterize user innovation toolkits. Figure 1 moreover provides an overview of these dimensions and depicts the assigned scales in detail. The dimensions are derived from the five basic elements. They are adapted based on the further findings of the literature review and the observations of the sample screening.

Both analyses showed, that the solution space has to be categorized more precise. Therefore, we split the original dimension of the solution space in the two parts shape and function. This has the advantage that both dimensions can be assessed independently and an overlap of the dimensions is avoided. Moreover, the range of manufacturing technologies which are used to realize the user design varies strongly. It thus, is another important distinguishing feature of user innovation toolkits.

Solution space (shape): The dimension of solution space in shape characterizes the degrees of freedom, which the toolkit offers to the user. With increasing degrees of freedom the innovation potential of the users can be better captured by the toolkit (Hippel, 2001).

A toolkit with a very small solution space only offers predefined shapes to select, while a more wide solution space allows the users to generate individual designs. We moreover distinguish between a 2-D and 3-D solution space and considers the amount of features, which can be manipulated by the users.

Solution space (function): The solution space of functions complements the solution space in shape. Only if a wide solution space in functions is offered, user innovations can exceed design aspects.

If functions can only be manipulated by an altered surface, we consider the solution space of functions to be small. While a medium size allows the variable combination of functions, a toolkit with a wide solution space enables the users to create new and individual functions.

Complexity of product: The complexity of a product is described by the number of its elements, their dependencies and diversity (Lindemann *et al.*, 2008). The complexity for examples influences development and manufacturing efforts. It represents the amount of knowledge and customer needs which are connected to the product. Thus, the complexity of the product which is innovated in the toolkit is an important characteristic. It influences both, the potential benefits of the toolkit and the complexity of the toolkit itself.

A product with very low complexity thus consists of one single component with few features and simple 2D-surfaces. More complex products have an increasing number of components and a 3D-shape.

Range of manufacturing technologies: The manufacturing technologies mainly determine the degrees of freedom in shape and function (Hippel, 2001). They grow with increasing range of

technologies and increasing flexibility. Moreover, to realize complex products a large range of manufacturing technologies is required (Reichwald and Piller, 2006).
The lowest value thus describes toolkits which only offer an online design function without manufacturing service. A small range of manufacturing technologies occurs, if only one technology is used to produce the user design. Instead, if a large range of technologies in combination with a flexible production system is provided, we consider this a large range of manufacturing technologies.
Producibility check: Demotivation of the user can occur, if he experiences too many failed attempts within the design process. Thus, a producibility check with immediate feedback is essential (Hippel, 2001).
We assign a toolkit which comprehensively checks, if the user design can be produced and if its functionality is ensured, to the highest value. Rough checks of stability or wall thickness are assigned to a medium one.
Trial-and-error completeness: A complete trial-and-error process is one of the main features of user innovation toolkits. Only a comprehensive support throughout the whole trial-and-error process can unleash the full innovation potential of the users (Hippel and Katz, 2002).
Thus, only toolkits which support all steps from first draft to the tested and ordered product are assigned to the maximum value.
User friendliness: Another important requirement is, that users are able to operate the toolkit without extensive knowledge or training (Hippel, 2001; Thomke and Hippel, 2004). Otherwise only the potential of lead users or experts can be assessed. Yet, the efforts needed to use and operate the toolkit depend on each individual.
Thus, we assessed these efforts by our own subjective impressions. Moreover, a toolkit which cannot be used without special 3D- or CAD-Software is assigned to a low user friendliness.

dimension	value		description
solution space (shape)	○	very small	selection of predefined shapes
	◔	small	2D, few features
	◑	medium	2D, many features and 3D, few features
	◕	wide	3D, many features
solution space (function)	○	none	no customization of functions
	◔	small	only by surface
	◑	medium	variable combination
	◕	wide	function creation
complexity of product	○	very low	one part, simple surfaces
	◔	low	one part, complex surfaces and few parts, simple surfaces
	◑	medium	few parts, complex surfaces
	◕	high	>100 parts, complex surfaces
range of mfg. technologies	○	none	no manufacturing technologies
	◔	small	one manufacturing technology
	◑	medium	few manufacturing technologies
	◕	large	many manufacturing technologies and flexible production system
producibility check	○	none	no check of producibility
	◔	rough	rough checks (thickness etc.)
	◑	advanced	advanced checks (simulation etc.)
	◕	comprehens	producibility is fully ensured
trial-and-error completeness	○	low	only rudimentary support in few aspects
	◔	partial	support in only few aspects
	◑	high	support in most important aspects
	◕	full	support in all phases
user friendliness	○	very low	other programms are required and usage is difficult
	◔	low	other programms are required
	◑	medium	operating all functions requires some efforts
	◕	high	easy to use, only few minutes to operate all functions

Figure 1. Dimensions of user innovation toolkits and their values

4 RESULTS

4.1 Characterization of user innovation toolkits

As result of the benchmarking analysis, Figure 2 presents the overview of all examined toolkits. Remarkably only toolkits with basic objects offer exhaustive degrees of freedom in the solution space (shape). In case larger degrees of freedom in shape are offered, the connected manufacturing technologies usually are limited to one flexible technology, for example 3D-printing or laser cutting. An extensive solution space in functions however, is only offered by the configurator. Existing toolkits for mechanical or mechatronic products do not offer the possibility to innovate functions.
Moreover, the configurator inherently ensures the producibility by only offering compatible configurations. But also some toolkits like “Trinckle” check the producibility and stability on an advanced level. They evaluate wall thicknesses and the stability through calculations or simulations.
Not all toolkits cover the whole trial-and-error-process. They either do not provide feedback on the user design or do not support the complete creation of the design. The assessment in the dimension of trial-and-error completeness seems to correlate with the user friendliness: Toolkits not covering the whole process often require additional software to realize a user innovated design. Besides that, most toolkits offer a reasonable amount of user friendliness.

		toolkit									
		Carfrogger	Cuboyo	Formulor	Jweel	Leopoly	Opel Adam	Sculpteo	Sculptgl	Thingiverse	Trinckle
feature	solution space (shape)	◑	◕	◑	◕	◕	○	◕	◕	◑	◕
	solution space (function)	◔	◔	◔	◔	◔	◑	◔	◔	◔	◔
	complexity of product	◑	◑	○	◔	◔	◕	◔	◔	◔	◔
	range of mfg. technologies	◔	○	◔	◔	◔	◕	◔	○	○	◔
	producibility check	◑	○	◔	◔	○	◕	◔	○	◑	◑
	trial-and-error completeness	◕	○	◑	◑	◑	◔	◑	◔	◑	◕
	user friendliness	◕	◔	◑	◑	◑	◕	◑	◑	◔	◔

Figure 2. Results of the benchmark analysis; user innovation toolkits and their dimensions

We propose to use radar charts to better visualize the features of toolkits. Figure 3 exemplarily depicts the benchmarked toolkits “Carfrogger”, “Jweel” and “Opel Adam”. This visualization allows to compare different toolkit concepts and to identify their strengths and weaknesses.
The seven dimensions are clustered according to their relatedness. On top and top right, the solution spaces which describe the degrees of freedom are positioned. The lower right corner groups the dimensions describing the complexity, while aspects concerning the user interface and the toolkit efficiency are located on the left.

4.2 General concept of “ideal” user innovation toolkits

The analysis of user innovation toolkits shows, that most toolkits are embedded in a community. Also the works of Parmentier and Gandia (2013) and Jeppesen (2005) point out the positive effect created by the connection of user innovation toolkits with a community. As Hippel (2001) as well depicts a library

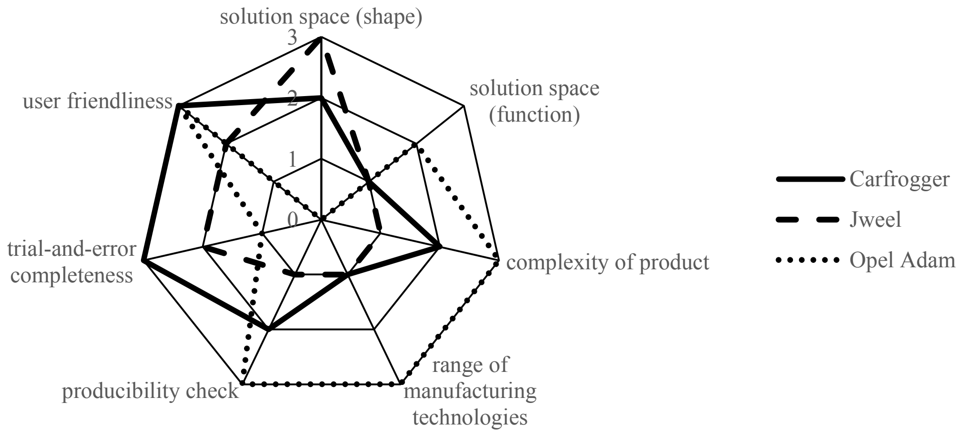

Figure 3. Radar chart of three exemplarily benchmarked toolkits

as one essential element of a toolkit, our concept suggests the combination of toolkit and community (in the following named OI platform). Thus, the concept involves the following four stakeholders:

- the user
- the OI platform
- the production system of the manufacturer
- the product development department of the manufacturer

The stakeholders are identified by a stakeholder analysis with experts from OI and manufacturers. For each stakeholder our concept defines the main use cases. In total ten abstract use cases apply for user innovation toolkits. Figure 4 visualizes them and depicts their dependencies and assignment.

The central use case from user perspective is to design an individual product. To improve user friendliness, we suggest two modes: the enhanced configuration of the product for users with low abilities and the comprehensive modification for users with advanced knowledge and abilities.

The second central element is the check on producibility and other restrictions. This use case is mainly associated to the product development departments and the manufacturing system. They define the restrictions to be tested and applied in the toolkit. Restrictions can have multiple origins, for example manufacturing abilities, functionality, product safety and strategic decisions.

To realize the described use cases and, our user innovation toolkit concept offers a set of basic function flows, described in activity diagrams. Figure 5 visualizes this diagram of the main use case "design individual product" and its extensions. Main features are the previously described two configuration modes as well as the automatic completion and producibility checks.

As described above, the two different modes help to satisfy the expectations of both, simple users and users with profound technical knowledge. It thus enables the development of toolkits, which can be used

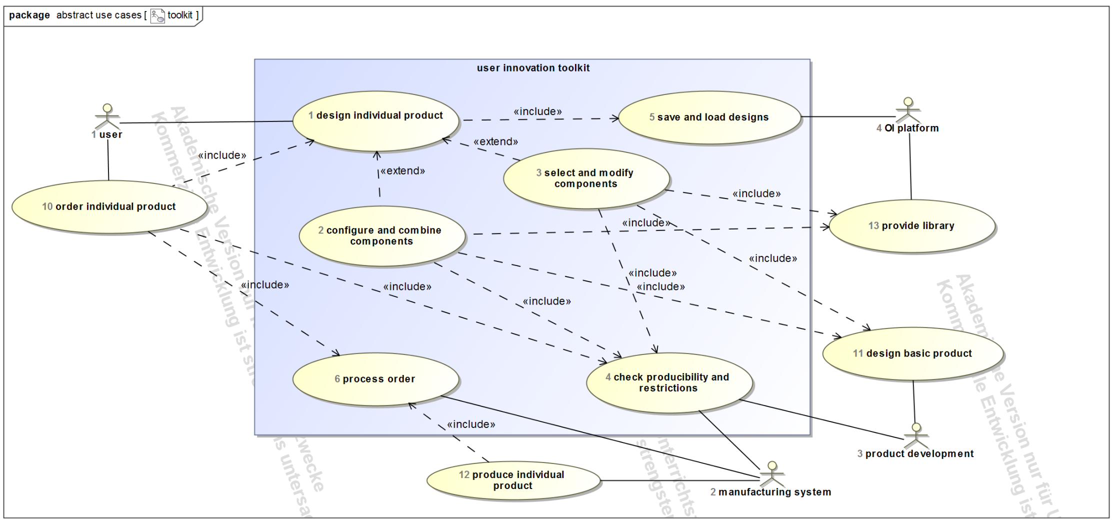

Figure 4. Use case diagram of the user innovation toolkit concept

to identify the customer individual needs of a large group and simultaneously unleash the innovation potentials of for example lead users. This variability helps to maximize the dimension of user friendliness and it simultaneously enables larger solution spaces.
The producibility check is integrated in the concept at two positions. A rough but immediate check of producibility after each manipulation through the user shortens the trial-and-error cycle and thus improves the efficiency of the toolkit. Moreover the detailed check which is only conducted on request, comprehensively ensures producibility. A report allows users to further improve their design. By that a second and larger trial-and-error cycle is implemented in the toolkit. These features maximize the toolkit's features in the dimensions of producibility check, user friendliness and trial-and-error completeness. The producibility check additionally is a necessary precondition for the price estimation: Only if it is clarified if the design can be produced and which materials or manufacturing technologies are involved, a realistic estimation of the final price can be made. Moreover, using that source of information, the pricing can include aspects as availability and capacity of the production facilities.
The third main feature is the automatic completion. To improve the trial-and-error process immediate feedback on user changes is necessary. Thus, an option to complete the product with standard elements is important, so that the users are able to evaluate their designs in context of the whole product. By that, user friendliness is further increased.
The concept in total includes similar activity diagrams for the other main elements: the check of producibility and the order process. It further provides detailed concepts of the most important elements. These are configuration of components, modification of components and the check on restrictions.

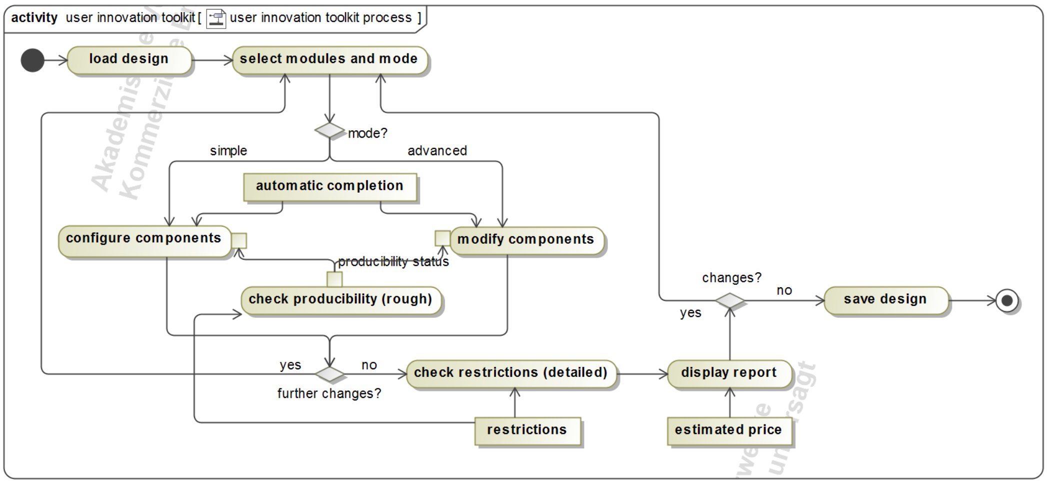

Figure 5. Top-level activity diagram of the use case "design individual product"

5 DISCUSSION AND OUTLOOK

The results of the benchmarking analysis clearly show the limitations of the application of user innovation toolkits. Existing applications are not able to combine a large solution space with a complex product and user friendliness. For the applications of user innovation toolkits it thus is important to find a suitable trade-off among the seven dimensions. The proposed radar charts improve this process and can help to match the toolkit concept to specific conditions.
However, the sample of ten toolkits could be enlarged. While public toolkits have been examined, especially non-public and company-internal user innovation toolkits can create further insights and reveal other best practices. Moreover, following only best practices will not necessarily result in an "ideal" user innovation toolkit. Further studies have to be conducted to comprehensively analyse and clarify the user needs.
The identified limitations of the application confirm, that current user innovation toolkit research does not sufficiently support their application. Nevertheless, the benchmarking revealed promising approaches and partial solutions. Based on both, research and application, our paper derives a general concept of user innovation toolkits. Starting from abstract use cases it can help manufacturers to derive

a tailored concept when developing a toolkit. However, even though design activities can be transferred to the user, the design and development of a user innovation toolkit requires large efforts. Especially the definition of restrictions and the implementation of producibility checks are expected to be challenging.

Moreover, the developed concept is not sufficient to improve the applicability of user innovation toolkits. Technologies and software have to be developed to provide solutions for the concept realization. In future research we will evaluate the concept by deriving and realizing a tailored solution. This might reveal further challenges and the concept will be adjusted accordingly. We also expect to clarify major directions for further toolkit research.

In summary this paper with its benchmarking analysis and user innovation toolkit concept supports the first steps of toolkit development. It helps to categorize existing toolkits, to evaluate trade-offs and to derive a toolkit concept for the desired application. Besides the further improvement of the concept another important field for future research remains: Not only the toolkits have to be fitted to the products, but also products have to be prepared and adapted to an innovation through toolkits.

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