INTERNATIONAL DESIGN CONFERENCE - DESIGN 2016
Dubrovnik - Croatia, May 16 - 19, 2016.

THE IMPACT OF USER-DRIVEN CUSTOMIZATION ON THE DEVELOPMENT PROCESS

M. Roth, C. M. Ulrich, M. Holle and U. Lindemann

Keywords: user-driven customization, design process, individual products

1. Introduction

During the last decades the expectations of customers strongly increased. At the same time factors like technological progress, globalization and demographic change lead to more diversified individual needs and heterogeneous markets [Piller and Stotko 2006], [Lindemann et al. 2006]. These factors drive an increasing demand for individual products and a shift of the value creation focus to customers or users [Reichwald and Piller 2006].

To react on these developments the manufacturers offer an increasing number of variants. Ideally, it is necessary to therefore identify each customer's individual needs [Piller and Stotko 2006]. However, this information is very difficult to obtain so that literature refers to it as "sticky information" [Franke and Hippel 2003].

The most common approach to meet the individual demands is mass customization. This includes a large variance through modules (hard customization) but also simple adaptions through distributers (soft customization) [Piller and Stotko 2006]. However, manufacturers struggle to access the relevant "sticky information" and all relevant individual needs [Hippel and Katz 2002]. While traditional approaches identify these needs in an exhaustive learning process, newer approaches try to integrate the user into the innovation process [Hippel and Katz 2002], [Franke and Hippel 2003]. Therefore, the field of Open Innovation (OI) [Chesbrough 2003] offers suitable concepts like user innovation and user co-creation [Franke and Piller 2004], [Reichwald and Piller 2006].

Combined with flexible production systems and especially with increasing capabilities of additive manufacturing systems (see [Gausemeier et al. 2013]), the co-creation and user innovation enable a new concept which we call user-driven customization. The idea is to offer a web-based OI platform with an integrated toolkit which allows the users to adapt and design the offered product according to their individual needs [Holle et al. 2014]. This individual product can be ordered and will be produced and delivered. While this user-driven customization is already applied for simple products like t-shirts (e.g. spreadshirt.de) and foils for cars (e.g. carfrogger.com), it is not yet realized for technical products [Roth et al. 2015b].

Even though a realization of this concept for technical products is obviously very challenging and requires changes in development and production. The existing literature does not yet examine these challenges. Thus, it is not clear at which point and which changes will be necessary to successfully offer user-driven customizable technical products. Therefore, this paper analyses the impact of user-driven customization. This knowledge can provide the base for the development of new methods and tools for a successful implementation of user-driven customization.

In the following, the paper first defines the concept of user-driven customization and elaborates its differences to classical mass customization. Moreover, the few existing research works on user-driven customization are presented and discussed as well as similar aspects in other concepts. Then, the research methodology is described before the main results are presented and discussed. The paper concludes with a summary of the implications and an outlook on further research.

2. Product customization

This chapter provides an overview of existing customization concepts and introduces the user-driven customization. Moreover, existing research on user-driven customization is briefly summarized.

2.1 Customization concepts

To realize individual products, various concepts exist. They can be differentiated by their level of customization and the point of user integration [Piller and Stotko 2003]. Figure 1 classifies the different concepts according to their level of customization and the point of user integration in the product lifecycle.

OI concepts try to integrate the users in the phase of product planning. Yet, currently fully individual products are usually realized by an engineer2order strategy. This means that large parts of the product are individually developed according to the specification of the customer. If the product is just individually produced for the customer, a make2order strategy is applied. Probably the most known strategy is assemble2order where standardized modules are individually combined in the assembly process. There, usually so-called configurators are used to handle the variance. The popularity of these systems underlines the demand for customization. Other concepts like match2order or bundle2order allow customization during sales and distribution only. Finally, adaptions by the user once he received the product can be called self-customization [Piller and Stotko 2003], [Baumberger 2007].

Another differentiation is proposed according to where the customization takes place: Hard customization takes place in the development and manufacturing processes while soft customization is done during distribution or at the user [Piller and Stotko 2003], [Baumberger 2007].

However, the demographic and technological changes mentioned in the introduction demand for an increasing level of customization but simultaneously for an increased involvement and self-actualization of the user. Figure 1 positions these demands and underlines that one existing concept cannot satisfy those. Therefore, user-driven customization will be introduced in the following.

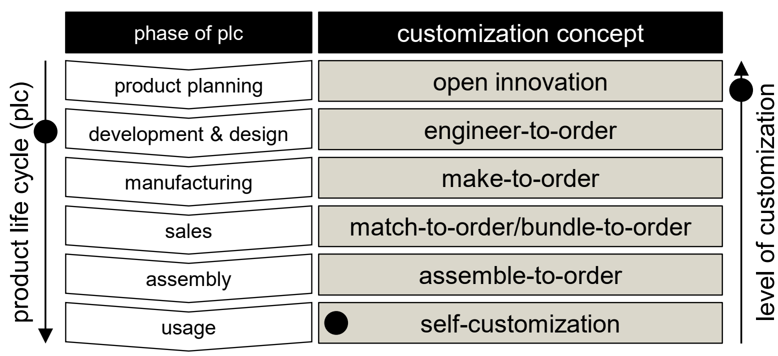

Figure 1. Existing customization concepts and current demands (black dots), adapted from [Piller and Stotko 2003], [Baumberger 2007]

2.2 User-driven customization

To satisfy the previously mentioned demands, a new concept is needed: User-driven customization combines the ideas of involving the user in the design phase and self-customization by the users. It thus unites hard and soft customization.

In user-driven customization a (web-based) toolkit is provided which allows the users to adapt and customize the product according to their needs. This customized product is then produced directly according to the user's design. An important differentiation to mass customization configurators is a not

pre-defined solution space. Theoretically the users can create an infinite number of different designs. Also they are able to undergo complete trial-and-error loops.
For complex technical products, this concept has not yet been realized. Figure 2 drafts an exemplary workflow for user-driven customization of a coffee machine. The user first designs his individual coffee machine in a web-based toolkit. He then submits his draft to the community, discusses it and exchanges ideas with other members. Based on that, he improves his design and finally orders it. The individual design then is directly transferred to the production planning system and is produced by a highly flexible production system. Finally, the customized coffee machine is shipped to the ordering user.

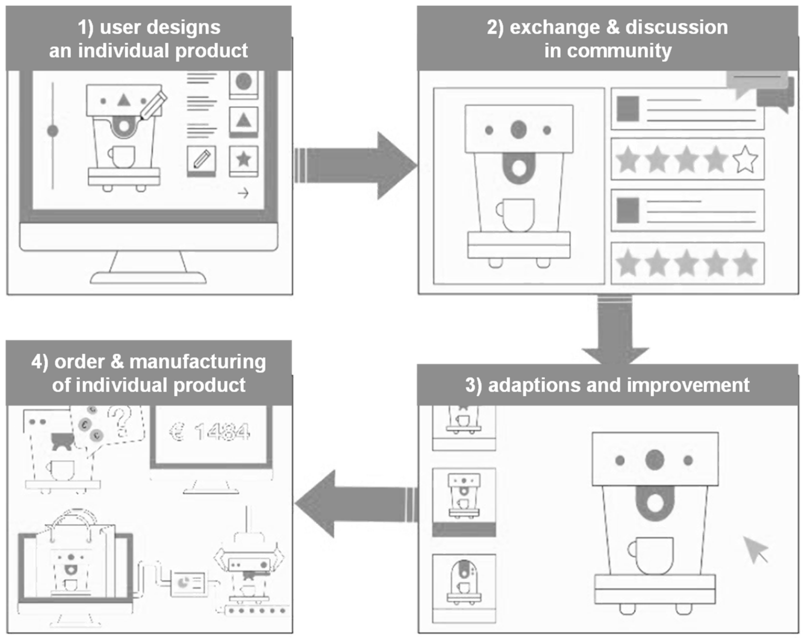

Figure 2. Workflow of user-driven customization of a coffee machine (source: Hyve AG)

2.3 Existing research on user-driven customization

As previously described, only few researchers yet worked on the field of user-driven customization. The general concept is similar to OI-principles like user innovation. E.g. Holle et al. describe the user-driven customization as transfer of user innovations to real products [Holle et al. 2014].
They also research methods to adapt the product architecture and product structure to this concept, as they identify a need for extensive preparation of the product in these aspects. This includes the growing importance of product architectures tailored to the specific levels of aspired customization [Holle and Lindemann 2014], [Holle et al. 2015]. Moreover, also increasing efforts and new challenges for safety analyses are identified, when the concept of user-driven customization is followed [Roth et al. 2015a].
With special focus on user innovation, requirements on toolkits, are researched. Their key elements are usability, offered solution space and completeness of the trial-and-error loop [Hippel 2001], [Roth et al. 2015b].
The previous sections underline, that the idea of user-driven customization partially is addressed by some researchers. Impacts on the design process are expected especially in terms of safety and product architecture. But since now, no work researches all possible impacts of user-driven customization on the design process. Therefore, this paper follows the research question "Which impact does user-driven customization have on the traditional design process?".

3. Methodology

In previous sections, the concept of user-driven customization was introduced. This section now explains the used research design and applied methods, to analyse user-driven customization's implications on the product development process.

3.1 Overview of the research methodology

As described in previous sections, the concept of user-driven customization of technical products is a new and still visionary concept. Without existing applications, experimental research or case studies cannot be applied. Thus, to answer the research question in this uncertain context, only an explorative study based on experience and expertise allows to derive valid conclusions.
Therefore, the main research instrument of this paper is an explorative study. Yet, the state of the art only gives a few hints on possible impacts but does not allow to derive a suitable set of hypotheses. Therefore, the research methodology combines a qualitative and quantitative exploration. The overview of the elements and their results can be seen in Figure 3 and will be explained in the following.

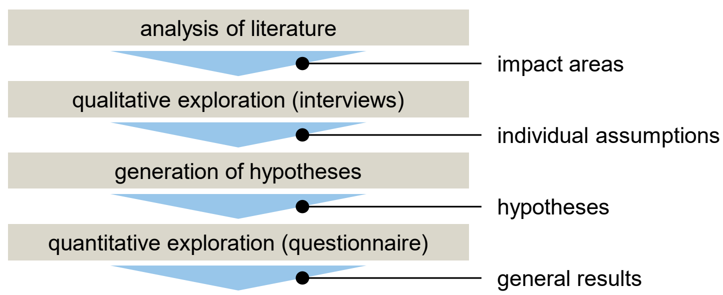

Figure 3. Overview of research methodology

The literature analysis was first of all used to clarify terms and to draw boundaries to other existing customization concepts. Moreover, it identified possible impact areas of user-driven customization.
This knowledge was then used to plan and conduct qualitative semi-structured interviews with four experienced product developers or consultants. From these interviews individual assumptions and expectations were obtained. These findings were in the next step consolidated to derive hypotheses, which resulted in a set of nine hypotheses to be researched. To test the formulated hypotheses an explorative questionnaire survey was conducted. To improve the quality of conclusions, the results of this web-based survey were then statistically analysed and interpreted with statistical methods. This was used to confirm or reject the hypotheses and to determine the impacts of user-driven customization.

3.2 Interviews

In the following, the methodology and the results of the interviews are briefly described.

3.2.1 Conduction of the interviews

The interviews were conducted as semi-structured interviews under the central question: "What are the impacts of a user-driven customization on the development process of technical products?". However, due to the novelty of the concept, the interviewees were first introduced to user-driven customization and the used reference model of the development process (V-model from VDI2206). Here, a general discussion on the concept was possible and open questions of the interviewees were clarified.
Then, the main part of the interview was conducted. It followed the mentioned central question and a semi-structured guideline with nine additional question items, which were derived from the literature survey and addressed both, general and specific aspects. The specific aspects were the impact on:

- phases of the design process: requirements, task clarification, system design, domain-specific design integration and ensuring properties
- cross-disciplinary tasks: scheduling and costing, risk management, configuration management

The four interviewees were selected according to the following criteria: similar position and profound knowledge of all phases of the product development process. Thus, the selected interviewees were all in a consulting or project management position. Designers would have implied the risk of a too narrow scope. Yet, two of the consultants had great experience and previously worked in management positions. The others were young professionals with a closer connection to trends and general developments.
The interviews were conducted in the natural environment of the interviewees (i.e. their company) and roughly took one hour. They were recorded with a recorder application and transcribed afterwards.

3.2.2 Results of the interviews

The first interviewee is quite sceptical on the success of user-driven customization. He especially points out the need for a flexible production system. In development he expects a need for extensive preparation and modular product structures. From his point of view, aspects like durability, functionality and safety have to be intensively considered from early stages. Thus, he expects increasing efforts and also emphasizes the need of a suitable pricing strategy.

The second interviewee also is sceptical on how to produce products customized by users. In development he emphasizes the need to cover all possibilities and provide borderlines or restrictions to limit the user to a space which can be handled. From his point of view this goes hand in hand with early considerations on quality, safety and their ensuring. But he also expects increased efforts for the testing and integration, as it might not be possible to apply standard procedures on individual products.

The interviewees three and four mainly focus on the development. They expect a modular product structure to be essential and also emphasize the need to cover all possibilities. In the same context they also demand for clear restrictions or borderlines: "A coffee machine shouldn't be changed into a juice press." Form their point of view also the test of acceptance will be difficult as they expect a gap between the users imagination and the product he will get. Similar to the other interviewees they also point out the challenge to ensure quality, compatibility, approval and to handle scheduling or pricing. They think it will only be possible to overcome this hurdles, when the design process is of strongly integrated nature.

3.3 Generation of hypotheses

The findings of the interviews were consolidated to form nine main hypotheses. If necessary, they were subdivided in sub-hypotheses to reduce the complexity of the assessment and to achieve more precise results. All hypotheses and derived sub-hypotheses are listed in the Table 1 together with explanations.

Table 1. Hypotheses tested in the survey

no.	hypothesis: With increasing user-driven customization,…	explanations
H1	…the needed interconnection and integration of development process phases also increases.	The interviewees mentioned that strict boundaries between the process phases may not exist anymore.
H2	…the required safety efforts especially in early phases also increase.	All the interviewees emphasized the important role of safety considerations, which is also identified by other studies (e.g. [Roth et al. 2015a]).
H3	…the efforts needed for the task clarification also increase.	Especially for the task clarification, the interviewees expected increasing efforts.
H4	…the need to define restrictions during the task clarification also increases.	Two of the interviewees explicitly mentioned the need to define borders/restrictions to limit the possible customization.
H5	…the relevance of quality (H5.1), safety (H5.2) and compatibility (H5.3) considerations during task clarification also increases.	All interviewees pointed out that the ensuring of relevant system properties during early phases will be essential.
H6	…the efforts involved in acceptance tests will decrease.	The interviewees did not find a consensus. While some expected increasing efforts due to the individuality, others expected less efforts due to the user involvement.
H7	…the need for continuous involvement of the users in the development process by suitable communication platforms also increases.	All interviewees emphasized the importance of continuous communication with the user.
H8	…the efforts for scheduling and pricing (H8.1) and the technical and economic risk (H8.2) also increase.	According to the interviewees, the unpredictability of the customization induces challenges and risks.
H9	…the need for complete and consistent documentation of safety analyses also increases.	This aspect was indirectly mentioned by the interviewees but also identified by literature [Roth et al. 2015a], [Lindemann et al. 2006].

3.4 Questionnaire survey

The previously defined hypotheses were tested in a web-based survey. Therefore, a questionnaire was developed which used in total 18 questions to anonymously obtain general information on the participants and their background as well as to test the hypotheses. To introduce the participants to user-driven customization, a comic (similar to Figure 2) was used, which describes the possible process flow. Furthermore, analogue to the interviews, the basics of the V-model were explained to provide a reference. Following that introduction, the questionnaire was structured in the following five sections:

- questions on professional experience and industrial sector
- questions addressing the whole development process and all general phases
- detailed questions regarding the task clarification
- questions on user involvement and other aspects
- employment information and professional background

The question items focusing on the impact of user-driven customization were mainly measured in an interval scale. The levels were described verbally with equal distance of the terms. The scales used five grades so that the middle one represents a rejection of the connected hypothesis. Questions with multiple answer items were sorted randomly and if suitable, fields for additional comments were provided.

To ensure the quality of the questionnaire a pre-test was conducted with eight participants familiar to the topic and one person without specific knowledge. It took them 10 to 15 minutes to completely fill the questionnaire and their feedback was used to improve and adapt the questionnaire accordingly.

For the main study, the questionnaire was hosted on a web portal. The survey started on 06th of August 2015 and lasted eight weeks. Invitations were distributed via email to members of the university's and institute's network. Additionally, the survey was posted in suitable groups of a social network.

The results of the study were then descriptively analysed and evaluated with the tool SPSS 22.0. There, also a test of significance was conducted. For the interval scales a 2-tailed t-test was applied.

4. Results

The following sections describe the results obtained from the questionnaire survey.

4.1 Sample of the survey

In total, more than 60 participants registered on the online platform. Out of them, 33 participants filled the questionnaire completely. Together with the participants who mostly filled the questionnaire, a sample size of N=44 was achieved. Figure 4 presents the composition of the sample regarding the background. It shows that the sample covers many sectors and is not dominated by one. Also the experience of the participants in a balanced way comprises young professionals and experienced ones.

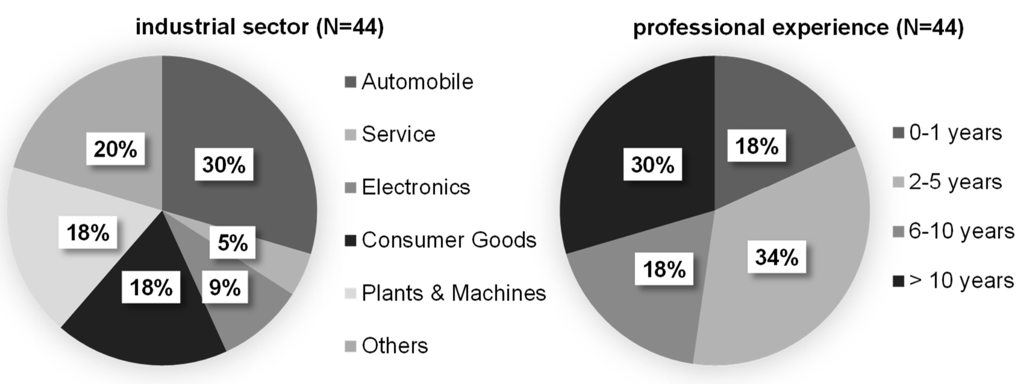

Figure 4. Composition of the sample of the questionnaire survey

A closer look on the professional background reveals that most of the participants are either involved in R&D (n=35%) or are in the position of project managers (n=25%).

4.2 Statistical results

Figure 5 summarizes the statistical results of the survey. In the following, the results on each hypothesis are briefly described.

hyp	item	dependent variable	Topic	N	mean	std. deviation	std. error mean	t	df	Sig. (2-tailed)	mean difference	95% confidence interval lower	95% confidence interval upper
H1	4	interconnection & Integration	integration	40	3,4750	1,15442	0,18253	2,6023	39	0,0130	0,4750	0,1058	0,8442
H2	5	safety efforts	task clarification	37	3,7838	1,03105	0,16950	4,6240	36	0,0000	0,7838	0,4400	1,1276
			system design	35	3,8286	1,07062	0,18097	4,5786	34	0,0001	0,8286	0,4608	1,1963
			system integration	35	3,8571	1,00419	0,16974	5,0498	34	0,0000	0,8571	0,5122	1,2021
			validation	35	3,3143	1,13167	0,19129	1,6430	34	0,1096	0,3143	-0,0745	0,7030
			equal in all phases	21	3,0000	1,09545	0,23905	0,0000	20	1,0000	0,0000	-0,4986	0,4986
H3	9	task clarification efforts	task clarification	33	3,7576	1,11888	0,19477	3,8895	32	0,0005	0,7576	0,3608	1,1543
H4	10	need for restrictions	system borders	32	4,0938	1,02735	0,18161	6,0225	31	0,0000	1,0938	0,7234	1,4641
			extensive product structure planning	32	3,6875	0,93109	0,16460	4,1769	31	0,0002	0,6875	0,3518	1,0232
			restricions covering all possibilities	31	3,3871	1,28264	0,23037	1,6803	30	0,1033	0,3871	-0,0834	0,8576
			maximal degrees of freedom	33	3,3333	1,33853	0,23301	1,4306	32	0,1622	0,3333	-0,1413	0,8080
H5	11	efforts for system properties	maintainability	33	3,5758	0,83030	0,14454	3,9835	32	0,0004	0,5758	0,2813	0,8702
			energy	33	2,9394	0,93339	0,16248	-0,3730	32	0,7116	-0,0606	-0,3916	0,2704
			reliability	33	3,2727	1,12563	0,19595	1,3918	32	0,1736	0,2727	-0,1264	0,6719
			recycling	32	2,8750	0,90696	0,16033	-0,7796	31	0,4415	-0,1250	-0,4520	0,2020
			quality	33	3,6364	0,99430	0,17309	3,6766	32	0,0009	0,6364	0,2838	0,9889
			functionality	33	3,7879	0,96039	0,16718	4,7127	32	0,0000	0,7879	0,4473	1,1284
			producibility	33	3,9091	0,91391	0,15909	5,7143	32	0,0000	0,9091	0,5850	1,2331
			campatibility	33	3,8485	0,93946	0,16354	5,1883	32	0,0000	0,8485	0,5154	1,1816
			conformity	33	3,8182	0,98281	0,17108	4,7823	32	0,0000	0,8182	0,4697	1,1667
			safety	33	3,7576	1,06155	0,18479	4,0996	32	0,0003	0,7576	0,3812	1,1340
H6	7	testing efforts	component tests	36	3,5000	0,84515	0,14086	3,5496	35	0,0011	0,5000	0,2140	0,7860
			integration tests	36	3,8611	0,79831	0,13305	6,4720	35	0,0000	0,8611	0,5910	1,1312
			system tests	36	3,7222	0,74108	0,12351	5,8473	35	0,0000	0,7222	0,4715	0,9730
			validation	32	3,1563	1,08090	0,19108	0,8177	31	0,4198	0,1563	-0,2335	0,5460
H7	12	need for user involvement	digital user communication	32	4,1563	0,88388	0,15625	7,4000	31	0,0000	1,1563	0,8376	1,4749
			extent of user service	31	3,7419	0,85509	0,15358	4,8310	30	0,0000	0,7419	0,4283	1,0556
			continuous communication	32	4,0938	0,92838	0,16412	6,6645	31	0,0000	1,0938	0,7590	1,4285
			feedback to users	31	4,2258	0,71692	0,12876	9,5199	30	0,0000	1,2258	0,9628	1,4888
			training of useres	32	3,5313	0,91526	0,16180	3,2834	31	0,0025	0,5313	0,2013	0,8612
			personal user communication	32	3,7813	1,00753	0,17811	4,3864	31	0,0001	0,7813	0,4180	1,1445
H8	13	benefit for general aspects	price structure	33	3,1212	1,11124	0,19344	0,6266	32	0,5354	0,1212	-0,2728	0,5152
			complexity	32	2,1563	1,19432	0,21113	-3,9964	31	0,0004	-0,8438	-1,2743	-0,4132
			pricing	32	2,5313	0,98323	0,17381	-2,6969	31	0,0112	-0,4688	-0,8232	-0,1143
			risk	33	2,6667	1,13652	0,19784	-1,6848	32	0,1017	-0,3333	-0,7363	0,0697
			certification	33	2,0606	1,11634	0,19433	-4,8340	32	0,0000	-0,9394	-1,3352	-0,5436
			scheduling	32	2,3750	1,03954	0,18377	-3,4011	31	0,0019	-0,6250	-0,9998	-0,2502
			efficiency	32	2,5000	1,21814	0,21534	-2,3219	31	0,0270	-0,5000	-0,9392	-0,0608
			quality	33	2,9697	1,01504	0,17670	-0,1715	32	0,8649	-0,0303	-0,3902	0,3296
H9	15	importance for documentation	safety	21	n.a.								
			basic functions elicitation	13									
			adaption processes	14									
			product structure analysis	13									
			none	5									

Figure 5. Overview of the statistical results

The first hypothesis H1 addressing the interconnection and integration of process phases is tested in question item 4. 55% of the participants agree or totally agree that with increasing user-driven customization the needed interconnection and integration of development process phases also increases. The values are different (significance 1.3%) to the test value (undecided). Thus, H1 can be accepted.

Hypothesis H2 which addresses safety efforts, tests their role in the different phases by five question items. For all the phases task clarification, system design, system integration and validation, the mean is above the test value. While for the validation phase the result is only 11%-significant the three earlier phases have a perfect significance level. This means, that with increasing user-driven customization the required safety efforts especially in the early phases also increases. This leads to the acceptance of

hypothesis H2. This result is consistent with the fact, that no significant results are obtained for the question item which states that the efforts will be equal in all phases.
In question item 9, the hypothesis H3 which in general assumes increasing efforts due to user-driven customization during the task clarification is tested. Here, approx. 67% of the participants expect higher or much higher efforts. Thus, the hypothesis H3 can be accepted on a very high significance level: With increasing user-driven customization the efforts needed for the task clarification also increase.
The items of question 10 tests hypothesis H4, which focuses on the need for restrictions. The results show, that the need for defined system borders and an extensive product structure planning during task clarification increases (perfect significance) when user-driven customization also increases. Thus, for system borders, hypothesis H4 can be accepted. For restrictions which cover all possibilities no significant results are obtained so that hypothesis H4 has to be rejected for comprehensive restrictions. The same applies for the maximization of the degrees of freedom.
Hypothesis H5 tested the efforts needed to consider and ensure system properties. The results for maintainability, quality, functionality, producibility, compatibility, conformity and safety are highly significant. This means, that with increasing user-driven customization the relevance of quality (H5.1), safety (H5.2) and compatibility (H5.3) considerations during task clarification also increases. This also applies for the other properties named before.
The hypothesis H6 addresses testing efforts. The results for these tests (component tests, integration tests and system tests) are highly significant. This means, that with increasing user-driven customization the efforts involved in these tests will increase. This contradicts H6 which expected a decrease. The actual acceptance test or validation delivers no significant results. Thus, H6 has to be rejected.
Hypothesis H7 states that with increasing user-driven customization the need for continuous involvement of the users in the development process by suitable communication platforms also increases. The survey results confirm this hypothesis: For all tested forms of communication an increasing need is predicted with at least very high significance (<0.3%). Thus, H7 can be accepted.
Hypothesis H8 expects drawbacks for general aspects due to user-driven customization. The results state that complexity, scheduling and certification aspects on a very high significance level and efficiency as well as pricing (H8.1) on a high significance level deteriorate due to user-driven customization. For risks (H8.2) only a 10%-significance level is reached and the upper boundary of the 95% confidence interval is above the test value, while the mean lies below. Thus, H8.1 can be accepted while H8.2 has to be rejected.
Hypothesis H9 was not tested on significance. Still the results show that 21 participants expect an important role for safety analysis documentation during user-driven customization. Also documentations on basic functions, adaption processes and the elicitation of basic functions are expected to be important. Only five participants expect no additional importance of documentation due to user-driven customization. Thus, H9 can weakly be accepted.
Additional to the test and rejection of H6, a possible correlation with the professional experience was examined. The high standard deviation of the answers leads to the speculation, if the experience influences the assessment of the participants. Yet, the results show no significant differences between the participants with less than five years of experience and with more than five years of experience.

5. Discussion

As the previous section shows, the results of the questionnaire confirm most of the hypotheses derived from the interviews. Additionally, the sensitivity analysis examining sub-samples of different experience levels did not reveal any differences so that the internal validity of the study can be considered as high.
In general it is necessary, that the single phases of the product development process are better integrated and interconnected to realize user-driven customization (see H1). This probably is connected with the positioning of user-driven customization in the field of customization concepts (see Figure 1). As the user is performing a type of self-customization which in turn is applied at the design stage clear borders between the phases can blur.
Also a suitable preparation figures out to be a key success factor when user-driven customization is applied. This results in increased efforts for the task clarification (H3). In this phase, the foundation for

the future customization has to be laid. This especially means that increased efforts will have to be undertaken to ensure quality, safety and compatibility (H5). These aspects are usually ensured in later phases but due to the unknown customization, they for user-driven customization have to extensively be considered already in this early phase.

Out of these aspects especially safety efforts will increase, as also the survey confirms increasing efforts in nearly all early phases of the product development for safety considerations (H2). The reason is that the solution space offered for customization has to be as safe as possible. In this context it is obvious that the connected documentation (general and safety) gains importance (H9) as these documents should be prepared for the customization and cannot be consolidated in later phases.

Besides all increasing efforts, the results of the questionnaire clearly state that it is not achievable to consider or cover all possible customizations by restrictions (H4). Yet, to limit this uncertainty to a manageable range it an extensive product structure planning and system boundaries are necessary (H4). While the first measure helps to separate customizable areas from critical areas, the second ensures a limitation of customization to a reasonable space and to preserve the actual nature of the product.

Moreover, for user-driven customization it is necessary to ensure a continuous integration of the users by multiple means of communication (H7). Remembering the close relationship between user innovation toolkits and user-driven customization this is not surprising. The communication and integration of the users are connected to requirements on the trial-and-error-cycle and on the usability for user innovation toolkits.

Yet, only hypothesis H6 cannot be accepted: It might not be the case that user-driven customization decreases testing efforts. Here different viewpoints already elicited during the interviews. While the early integration of the users might decrease testing efforts concerning the general acceptance, they simultaneously might be increased as the users usually are not experts and thus are not able to design the product according to their expectations on the first attempt. Besides the acceptance, the efforts needed for e.g. integration tests might increase (H7). This is strongly connected to the increased efforts for safety, quality and compatibility: The unknown customization result makes it impossible to prepare standard testing procedures.

Finally, it was stated in the interviews, that user-driven customization increases the technical and economic risk. The survey cannot prove this assumption (H8). However, the changing markets and increased competition might force companies to take the risks and realize user-driven customization to gain competitive advantage. Therefore, the increased efforts for safety, quality and compatibility can help to minimize additional risks. This balancing of risks might also be the reason for a non-significant result of the hypothesis as some participants might increase their focus on the chances instead of risks.

6. Conclusions and outlook

This paper in a combined qualitative and quantitative survey explores the impact of user-driven customization on the design process. From the interviews nine hypotheses on the impact are derived and tested in a questionnaire survey. While most hypotheses are accepted the impact on acceptance tests cannot be determined. In summary three major implications of user-driven customization are identified:

- The integration of the product development process phases needs to be improved.
- A suitable preparation of the customizable product is essential. This includes extensive product structure planning and definition of boundaries.
- The early consideration of system properties gets crucial. Aspects like safety, quality and compatibility have to be intensively considered starting from early phases to reduce the impact of the uncertainties and risks induced by the customization.

These key findings build up on assumptions of experts. They have been validated by a small but suitable sample. However, a larger sample for the interviews and for the questionnaire would improve the validity. Still, many uncertainties might have negative impact on the external validity of the results. The explorative study presented in this paper thus, gives hints on the answers of the research questions, but does not yet fully answer them. To further examine the implications of user-driven customization, practical examples are needed. There the hypotheses can be tested with hard data and thus, the validity can be increased. This paper therefore contributes by providing general impacts and hints which can help to further and more precisely examine the concept of user-driven customization.

Moreover, the questionnaire and interviews were conducted with reference to the V-model. It represents a valid state of the art of the product development process. Yet, other process models (e.g. agile models) might be better suited for user-driven customization. The implications on these processes have to be tested in future research to identify the most suitable process base for user-driven customization.
Besides these limitations, it gets clear that sufficient preparation and the early consideration of system properties is needed for user-driven customization. Future research has to develop methods and tools which for example support the product structure planning or the ensuring of safety and quality.

Acknowledgement

We thank the German Federal Ministry for Economic Affairs and Energy for funding this work as part of the collaborative research project "InnoCyFer - Integrierte Gestaltung und Herstellung kunden-innovierter Produkte in Cyber-Physischen Fertigungssystemen" and all interviewees and participants.

References

Baumberger, G. C., "Methoden zur kundenspezifischen Produktdefinition bei individualisierten Produkten", Dr. Hut, München, 2007.

Chesbrough, H. W., "Open innovation - The new imperative for creating and profiting from technology", Harvard Business School Press, Boston, 2003.

Franke, N., von Hippel, E., "Satisfying heterogeneous user needs via innovation toolkits: the case of Apache security software", Open Source Software Development, Vol.32, No.7, 2003, pp. 1199–1215.

Franke, N., Piller, F. T., "Value creation by toolkits for user innovation and design: The case of the watch market", Journal of Product Innovation Management, Vol.21, No.6, 2004, pp. 401–415.

Gausemeier, J., Wall, M., Peter, S., "Thinking ahead the future of additive manufacturing: Exploring the research landscape", Heinz Nixdorf Institute, University of Paderborn, 2013.

von Hippel, E., "Perspektive: User toolkits for innovation", Journal of Product Innovation Management, Vol.18, No.4, 2001, pp. 247–257.

von Hippel, E., Katz, R., "Shifting Innovation to Users via Toolkits", Management Science, Vol.48, No.7, 2002, pp. 821–833.

Holle, M., Lindemann, U., "Design for Open Innovation (DfOI) — Product structure planning for open innovation toolkits", Selangor Darul Ehsan, 2014.

Holle, M., Maisenbacher, S., Lindemann, U., "Design for Open Innovation individualization-oriented product architecture planning", 9th Annual IEEE International Systems Conference (SysCon 2015), IEEE, Piscataway, 2015, pp. 397–402.

Holle, M., Roth, M., Gürtler, M. R., Lindemann, U., "From Customer Innovations to Manufactured Products: A Project Outlook", International Journal of Mechanical, Aerospace, Industrial and Mechatronics Engineering, Vol.8, No.4, 2014, pp. 1078–1082.

Lindemann, U., Reichwald, R., Zäh, M. F., "Individualisierte Produkte-Komplexität beherrschen in Entwicklung und Produktion", Springer, Berlin, 2006.

Piller, F. T., "Mass customization - Ein wettbewerbsstrategisches Konzept im Informationszeitalter", Deutscher Universitätsverlag, Wiesbaden, 2006.

Piller, F. T., Stotko, C. M., "Mass customization und Kundenintegration - Neue Wege zum innovativen Produkt", Symposion Publishing, Düsseldorf, 2003.

Reichwald, R., Piller, F. T., "Interaktive Wertschöpfung - Open Innovation, Individualisierung und neue Formen der Arbeitsteilung", Gabler, Wiesbaden, 2006.

Roth, M., Gehrlicher, S., Lindemann, U., "Safety of Individual Products - Perspectives in the Context of Current Practices and Challenges", Proceedings of the 20th International Conference on Engineering Design (ICED 15), Vol.3: Organisation and Management, Milan, Italy, 2015a, pp. 113–122.

Roth, M., Harmeling, J., Michailidou, I., Lindemann, U., "The 'Ideal' User Innovation Toolkit - Benchmarking and Concept Development", Proceedings of the 20th International Conference on Engineering Design (ICED 15), Vol.9: User-Centred Design, Design of Socio-Technical systems, Milan, Italy, 2015b, pp. 249–260.

Michael Roth, Dipl.-Ing. M.Sc.
Technical University of Munich, Institute of Product Development
Boltzmannstr. 15, 85748 Garching, Germany
Email: michael.roth@pe.mw.tum.de