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DESIGN FOR FLEXIBILITY: MAKING PROVISIONS FOR REQUIREMENT CHANGES

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ABSTRACT
Product development is strongly affected by changing environments, tighter requirements and uncertainties. One idea to handle these challenging conditions is to keep the product flexible to allow for easy adaptation to new requirements and functions. We analysed various approaches dealing with this topic in order to form a set of 23 design guidelines, that support the development of this type of design. The guidelines were evaluated with two different research methods. First, participant observation was used to obtain direct information about the use of the design guidelines. Second, a laboratory study was undertaken with engineering students, who had to work on a design problem. One group was instructed with the guidelines before the test and compared to a group working without instructions. The results show that the idea of keeping the product flexible from the beginning is a useful approach and that the guidelines help to create these kind of products. However, it was also found that differences between working with and without the guidelines are small. We assume that the guidelines have to be defined more precisely and adapted to the product development context in order to form a useful tool. This is part of further research.

Keywords: Design guidelines, flexibility, adaptability, changes, participant observation, laboratory study

1 INTRODUCTION

1.1 Motivation
The product development process nowadays is affected by rapidly changing, global markets, new competitors and a fast growing number of technical possibilities. Newly developed products must be designed not only to meet the customer requirements, as well as the companies goals and constraints, but they have to be designed pertaining to the entire life cycle. To meet market needs in highly dynamic markets, companies have to reduce their development times, while increasing their responsiveness to changing markets by adapting their development efforts constantly towards what are essentially are moving targets [1].
In this challenging context products have to be designed, tested and produced in shorter and shorter time, while at the same time the economic constraints become increasingly restrictive. Requirements are evolving rapidly within the product life cycle in terms of number and performance of available functions. With more complex functions and a higher variety of users in our globalised context, products tend to become more complex and individual at the same time.
Likewise the product development process becomes more complex. Fast changing requirements cause a higher number of iterations. More possibilities and options for the customer indicate more activities and decisions during the development phases, which, as stated earlier, are becoming shorter. Thus, it is more likely to make the wrong decisions and create products, that do not fit the customers' requirements and therefore have to be redesigned. The higher probability of changes during the product life cycle adds to the many uncertainties that already exist at the beginning of the product development process [2].
A further complicating factor for certain products, in particular those based on new technologies, is that some of the requirements cannot be known yet, because the related knowledge is not available yet. For example, we are involved in a product development and research project in which a bioreactor for

the cultivation of cells has to be developed. The idea is to use foamed aluminium oxide ceramics, in whose pores the cells can grow. These ceramics are new materials with a widely adjustable range of characteristics. As most of the characteristics are still to be analysed, the use of the foamed ceramic structures causes many uncertainties for the development of the bioreactor. Many requirements are unknown at present and can only be found through tests for which at least a prototype of the bioreactor is needed. This obviously requires the bioreactor to be developed. Starting over and over again after each test is not efficient and – and in this case – not even possible within the time available. In order to avoid costly and time-consuming trial-and-error redesign loops in this type of development projects, the classical product development approach as e.g. proposed by Pahl/Beitz [3] has to be adapted to these new challenges.

1.2 Objective

In order to handle the rapidly changing requirements during the product development process and deal with the related uncertainties as described in section 1.1, we propose an approach based on "flexibility". The assumption is that by keeping the design flexible and leaving the option of adapting to new functions open *during development*, the probability of redesign can be lowered and the impact of requirement changes can be limited.

For our approach we will propose, test and discuss a set of guidelines, which shall support product developers, in addition to the existing tools, methods and methodologies, to develop a flexible product in order to react easily and fast when requirement changes occur during the development process. Moreover the guidelines can be helpful, when the product developer has to handle uncertainties, because customer requirements are yet unknown, are changing faster than the new product can be developed, or when the impacts of new technologies, materials and processes can only be estimated.The approach is tested in a participant observation development project and in a laboratory study with engineering design students.

2 RELATED RESEARCH

Many different terms, such as flexibility, changeability, versatility and adaptability can be found in literature to describe a very similar but not identical aspect of the product development process and of the product. In the following, "flexibility" is used as a generic term covering these different terms and their underlying ideas. Often the related research focuses on one single aspect of flexibility, namely the ability of a product to suit customer requirements, if these vary substantially or change fast. Many ideas of the related research thus concentrate on the product specification and on the embodiment and structure of the product when it is on the market (either to allow changes during the product's life or to allow individualisation of the product). They do not focus on the flexibility of the product while it is being developed to be able to deal with as yet unknown requirements.

The idea of remaining flexible (in a generic sense) throughout a product development process in a rapidly changing environment and thus remaining competitive was already proposed by Thomke and is still the focus of current research [4]. His work is more on a generic level. He does not propose guidelines or tools for product developers, but focuses instead on the importance of agile acting and reacting during the product development process [5, 6].

Palani Rajan et al. define flexibility as the degree of responsiveness (or adaptability) for any future change in a product design [7]. In their work on Design for Flexibility (DfF) a method of measuring the product's flexibility is presented and it is demonstrated how FMEA can serve as a useful analogy to address the problem of evaluating product flexibility. They explain the utility of Change Mode and Effects Analysis (CMEA) as a systematic aid in understanding how some future change might affect a product. They developed flexibility guidelines for designers to evaluate a product and to change the design based on the results from the CMEA.

Modularity is one of the most important issues in research on flexible products [eg. 4, 7, 8, 9]. The Modular Function Deployment (MFD) as presented by Erixon [9] is used to modularise the product. The division of a product in modules allows the product to be changed more easily, for example to be adapted to new requirements, because the changes can be made on module level and do not necessarily affect the whole system. Design for Modularity does not give precise instructions to design the modules of a product, but it is used to define useful modules and interfaces between them. Sosa et al. propose modular design not only on assembly level, but as well on system level [10]. A useful modularisation of products is of high importance, because it is the basis for new products and variants.

The concepts of product platform and product architecture are strongly related to the modularisation concept. Hölltä-Otto defines modular product platforms as sets of common modules that are shared among a product family. She does not only present a tool to identify alternative common modules but also presents a multi-criteria platform scorecard for improved evaluation of modular platforms [11]. Design for Variety (DfV) is a similar approach to design products to meet customer requirements [12]. The idea is to build a series of similar products based on the same product architecture. Martin and Ishii [12] quote Ulrich, who defines architecture as a scheme by which the function of a product is allocated to physical components [13]. Using their DfV approach, it is possible to create a great variety of products with minimal design effort, so that many different customers can be served. The product architecture is of high importance, because it is basis not only for one product, but for a series of different products, which is similar to the product family as mentioned by Hölltä-Otto. Van Wie describes a systematic method for creating a useful product architecture for the concept of DfV [14]. He differs between two types of driver causing redesign: internal drivers (eg. a change from one concept to another) and external drivers (eg. shifting customer needs). To avoid redesign, the DfV method prescribes steps and heuristics for developing a product architecture less sensitive to future changes.

There are different interpretations of the concept of Design for Changeability (DfC). While Schuh et al. [15] focus on the flexibility of the production process and its machinery, Fricke et al. present different “principles to enable changes in systems throughout their entire life cycle” [8]. As products are part of systems and can have a comparable high complexity, the distinction between products and systems is neglected here and the presented principles are transferred from systems engineering to product development. Fricke et al. develop the idea of incorporating changeability into a system architecture. Flexibility, agility, robustness, and adaptability as four key aspects of changeability are defined and described. To achieve changeability in a system, they propose several design principles.

Design for Adaptability is presented by Hashemian with a focus on the extended utility of products [16]. He describes a way of designing products that can be adapted to different requirements with a specific and a general Adaptable Design (AD) approach. Specific AD is proposed to be performed first to take advantage of available forecast information, and then general AD has to be performed in order to increase adaptability to unforeseen changes. Methods and guidelines, which help to design adaptable products, are proposed as well as a measure for the assessment of adaptability.

Besides the approaches of creating a flexible design with specific methods an guidelines, there is the idea of using special parts to create products that autonomously adapt to changed situations. This concept, called adaptronics, aims at developing construction structures that continuously fulfil their tasks by actively adapting themselves to changes in loading and required functionality by integrating actuators and sensors in the construction structure as multifunctional materials [3]. Thus combining mechanical structures with control and information technology [17].

All approaches that are mentioned above deal with the idea, that products have to be designed in a flexible way in order to deal with the great variety in requirements (individualisation) or to handle fast changing requirements during product life. Some offer precise instructions for the development of a new product. Other approaches are more abstract and less practical when solving a concrete development problem. None of the analysed methods deals with designing a product, i.e. gradually fixing its properties, while at the same time keeping the options open to remain flexible during the product development process. Therefore a new approach, Design for Adaptability, is presented to handle the problem of changing requirements and managing uncertainties during the product development process. This approach is centred around a set of guidelines.

3 APPROACH

3.1 Flexible product design

One aim of the proposed idea of keeping the product design flexible, changeable and adaptable is to reduce the costs of changes. A flexible product design, allows easier and fast adaptation to changes. The rule of ten is a commonly known description of the relation between costs of changes and the time when changes occur [18]. With every phase later in the product development process or product’s life, the costs for changing the product increases by a factor ten. Keeping the design flexible and thus making changes and adaptations of new function easier, the rule of ten can hopefully be changed to the rule of ten minus x as presented in figure 1. Thereby x indicates the effects of a flexible product design on the complexity and costs of the change. In order to achieve these positive effects we propose to work with a set of selected guidelines (see section 3.2) in the product development phase, because here the trend is set for the whole product life cycle.

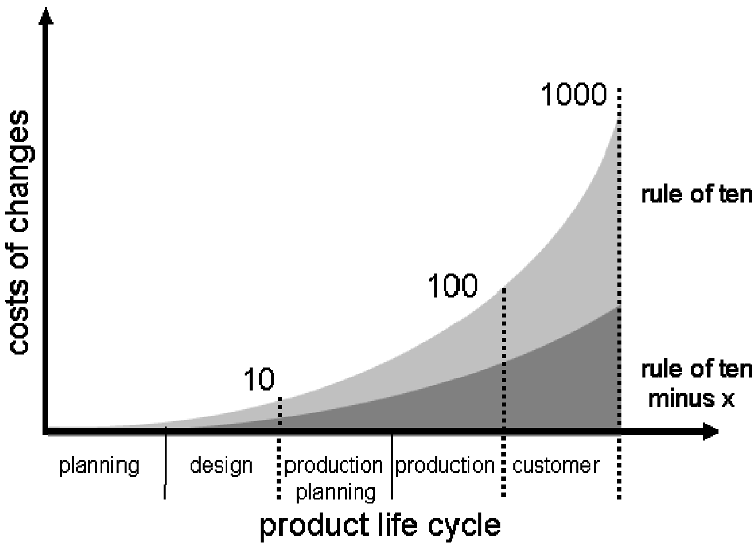

Figure 1. Rule of ten and its modification

Figure 2. illustrates one mayor benefit, that is hopefully achieved by designing flexible, changeable and adaptable products right from the start of the development process. The progress of development the should then be less affected when changes (within limits) occur when developing a new product. Using this approach products can be developed faster and the results may even be better.

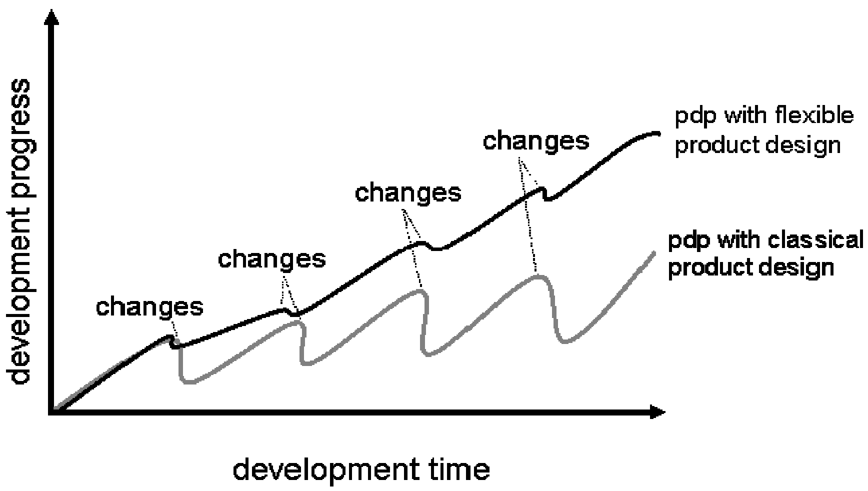

Figure 2. Work progress when designing (un-)flexible products (pdp = product development process)

Different methods that are used to create any kind of flexible products (see section 2) were analysed in order to create a new approach. To achieve a flexible, changeable and adaptable product design, we propose the use of design guidelines which are used in addition to classic product development methods and methodologies like Pahl/Beitz and Ulrich [3, 13]. The most suitable guidelines from the related research approaches were chosen and put into the new context of flexible, changeable and adaptable design.
At present the approach is fairly generic, it therefore can be used for all kind of products.

3.2 Design guidelines

Guidelines are formulated to advise people on how something should be done or what something should be [19]. The aim of using these in product development is to make the results of the activities of product developers more predictable and probably of higher quality. The guideline we have selected from the existing approaches as being suitable for our approach are clustered in seven groups. The numeration below is of no specific order as at present all guidelines are considered equally relevant for the approach:

Independent modules

A.1 introduce/increase modularity of the design (separated by functions)
A.2 increase number of divisions
A.3 aim for autonomous modules
A.4 reduce internal cross linking/use bus systems
A.5 reduce internal dependencies (incl. power dependencies)

The idea is to separate the product by its functions into a high number of modules. By reducing the links and the dependencies between the single modules through the creation of autonomous modules, the effect of changes is limited to single parts/modules of the product and does not necessarily require redesign of the whole product. Moreover the modular layout allows building different products out of a set of pre designed modules. This makes adaptation to new functions easier as these new functions can be integrated in new modules, that can be connected to the product later.

Buffer zones and oversizing

B.1 create buffer zones
B.2 oversize related to power
B.3 oversize related to strain
B.4 oversize related to space

Designing the product with buffer zones and oversizing it in various ways, reduces the probability of redesigning parts or the whole product, when requirements are defined more precisely in later phases of the product life cycle. The buffer zones (e.g. a hollow space in a cage of a vacuum cleaner [7]) provide space to implement new functions, parts or modules without changing any other part of the product.

Standardisation

C.1 define a limited set of interfaces early
C.2 use standardized parts/set own standards (limited number of different parts)
C.3 "freeze" if possible
C.4 design first input/output, later internal mechanisms

The early definition of interfaces and the use of standardized parts simplify the changing process later on, because the product developer only has to deal with a limited number of interfaces and connecting devices. Freezing specific parts means not to allow changing the frozen designs once they are defined. Thus these designs will not be source of changes for other parts later on during the whole life cycle. Designing first the input/output mechanisms and care about the internal mechanisms later relates to the precise definition of the interfaces of the modules.

Additional functions

D.1 select technology, which is far from obsolete
D.2 plan additional functions and features from the start
D.3 aim for „add-ons“
D.4 place obsolescing/wearing parts at the outside
D.5 plan „custom-features“ at the outside of the product

Selecting technology, which is far from obsolete, and planning additional functions will reduce the probability of changes in the product life cycle. Placing parts with a high probability of changes, like wearing parts or custom parts, at the outside of the product simplifies the change process.

Parametric design

E.1 use parametric design

Using parametric design (e.g. parametric CAD-Systems) enables the easy change of the whole product in terms of scaling geometric dimensions. The change complexity is much smaller than with a non-parametric design.

Simple change procedure

F.1 plan unambiguous (dis-)connection techniques (plan disconnecting)

F.2 aim for self-adjusting and self-healing designs

F.3 use flexible (change-tolerant) designs/machine elements

When the possibility of changes is high, the products have to be designed in a way, that these changes can easily be implemented. Therefore unambiguous (dis-)connection techniques have to be accurately planned. Self-adjusting solutions and machine elements tolerant to change (e.g. slotted holes) help to simplify the changing procedure as well.

Software functions

G.1 implement software instead of hardware solutions

By implementing functions with software solutions instead of hardware later changes can sometimes easier be adapted and products can be adjusted with software updates over its life cycle. In many cases it is easier to change the software instead of redesigning the hardware of a product.

All the guidelines shall help to design a new product more flexible to handle requirement changes and uncertainties in the product development process. They partly propose contrary solutions, so the product developer has to decide, which one is more important for the situation at hand. Some guidelines have to be handled with care, so as not to come into conflict with other requirements, such as the guideline on oversizing which will conflict with requirements on space and weight reduction.

4 EVALUATION

In order to evaluate the use of the selected guidelines the following hypotheses (H) and research questions (Q) were formulated:

H1: The guidelines help to handle changes during the design process faster

H2: The guidelines help to adapt to new requirements causing less costs

H3: The guidelines help to create better quality products, if changes occur

H4: The guidelines support the designer during the whole process

H5: Using the guidelines keeps the designer motivated, if changes occur

Q1: During which stages are the guidelines used?

Q2: What changes are not supported by the guidelines?

Q3: What are the side effects of using the guidelines?

Q4: Can new guidelines be derived from the evaluations?

In order to evaluate the set of guidelines two evaluation methods were used: participant observation and a laboratory study.

4.1 Participant observation

Active participation in a product development project and constantly reflecting on one's own process can lead to deeper understanding of the complex problems and dependencies of product development. In the first evaluation this method of participant observation is used: the researcher is at the same time the product developer using the guidelines. On the one hand there is the disadvantage of subjectivity, but on the other hand there is the possibility of deep insight into the use of the guidelines and fast realisation, specification and analysis of new ideas for improving the guidelines. Participant observation started one year ago and is still ongoing. The first author is participating as the product developer in the bioreactor development process described in section 1.1. Due to the innovative character of the device, the whole project is affected by fast changing requirements and a high number of uncertainties. The bioreactor is developed for actual use by other researchers in the group. The use of the reactor allows the evaluation of the quality of the product.

All data was collected in a diary: Work progress and experiences with using the guidelines were written down every day. This data was used to evaluate the benefits of working with the guidelines, when the first version of the bioreactor was built. The participant observation was also used to concretise the research questions and hypotheses, that mainly played a role in the second evaluation, a laboratory study involving several student designers.

4.2 Laboratory study

The laboratory study involved the analysis of the application of the guidelines in a product development process, in which a part of the bioreactor mentioned in section 1.1 had to be developed. The participants were 10 students, who had been studying for 2½ to 5½ years at the department of Mechanical Engineering and Transport Systems. Each one of them was given a list with about 30 requirements. They were each requested to develop the product on their own within 3 hours. Results had to be detailed hand sketches, if necessary supported with written explanations. All documentation produced during the development process (see e.g. Fig.3.) was collected for further analysis. The experimental group (5 of the students) was instructed about the set of guidelines before the study started in a presentation of half an hour. The control group (5 students) started the development process without further instructions. After one and a half hour, 5 of the requirements were changed to more complex/more restrictive ones and 2 new requirements were added to be able to investigate the reactions to change.
A short questionnaire to be completed directly after the requirements were changed, asked participants about their motivation and their feelings about their progress. Another more detailed questionnaire was handed out after the students finished their designs and provided more in depth information about when, why, and where the guidelines were used and what problems the students had, when the requirements were changed. The design time was measured for those participants that finished before the 3 hour time limit, in order to see if working with the guidelines can accelerate the process. Photo documentation of the work was done every 20 minutes to observe progress.

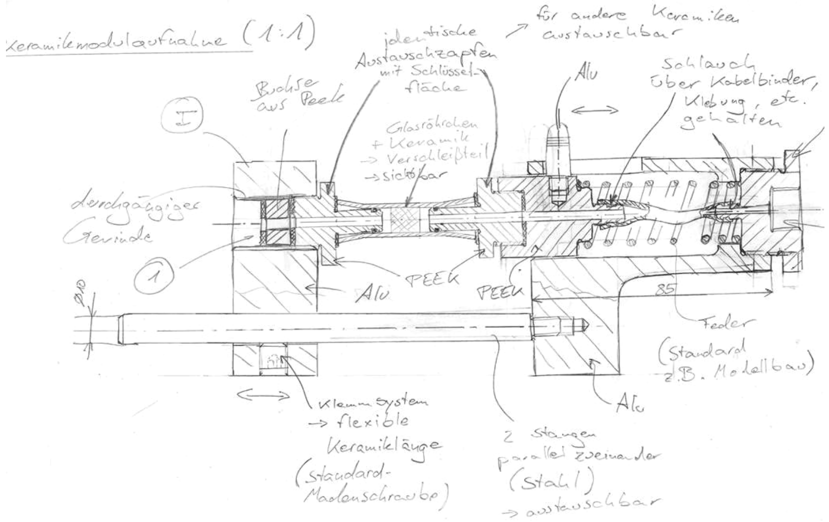

Figure 3. Drawing made by one of the participants

Questions during the study were only answered if they were directly related to the understanding of the requirements or the questionnaires. The same answers were given to all participants. All questions and answers were documented. Sketches, drawings and additional documentation were analyzed by a team of engineering design PhD students with extensive background in teaching engineering design.
The study was exploratory. The results will be used to prepare a more comprehensive evaluation with more specific guidelines and more participants.

5 RESULTS

The results presented here provide a first evaluation to assess whether the proposed concept has any merit. Though exploratory, the results show some interesting tendencies.

5.1 Results of the participant observation

The generated set of guidelines was used for the development of a bioreactor which had many changing requirements and, due to its new concept and materials involved, a large number of uncertainties.

In the beginning the individual modules were defined using a function structure based on the functions taken from the list of requirements (guidelines A1, A2). The whole design was simplified by using several standard parts (C2). Standardized interfaces were designed that could be used to take up additional functions later on (C1). Parts (subsystems) were dimensioned much bigger than calculated to leave space for later functions. The buffer zone guideline (B1) was applied for the housing of the bioreactor. Oversizing of power parts (B2) was used when designing the heating system.

One task in the design process was reducing the interdependencies of the single modules of the system especially of all components made of the new material, because a majority of their properties were unknown when designing the product. Therefore the design of these parts was defined (“frozen”, C3) in the early phase of the project so that precise interfaces could be defined as well. As a consequence, sensitive parts could easily be separated and decoupled from the other modules.

The modular design (A1) of all assemblies could have allowed for easy adapting in case the early design freeze was suboptimal, which turned out not to be the case. When requirements changed or new ones were added the product design could – most of the time – be adapted easily and fast ,. Standardized interfaces helped to adapt the design to new functions without changing the overall design of the device.

Due to the lack of comparisons, the hypotheses H1-H3 cannot be answered using the participant observation study. More research has to be done with other products and other product developers. It was possible to confirm that guidelines could be used within all phases of the product development process (H4). The guidelines were used everywhere, whenever it was possible – on system level as well as on part level (Q1). During the one year this participative observation is now running, it was not possible yet to answer what kind of changes and uncertainties are easier to handle, when the product is designed with the given guidelines. It was also not possible yet to determine what changes can not be adapted with the flexible product design (Q2). As a negative side effect, the whole design seems to get more complex, if the focus is on flexibility. Moreover, there is a negative feeling concerning the postponement of decisions instead of taking them immediately in the early phases of the product development process (Q3). Based on the experience of the project, new guidelines were proposed, which were integrated in the list as shown chapter 3 (Q4).

5.2 Results of the laboratory study

When analysing all drawings and sketches that were made by the students, the following results attracted our attention:

Based on the assessment of the group of evaluators, the designs developed by the experimental group are slightly better, fulfilment of the requirements, than the ones of the control group (H3). But the designs of the experimental group tend to be more complex compared to those of the control group, meaning that they have more parts and more complex geometries. Analysing the progress of the product development process, it became clear that the experimental group spent more time in the early design phases, when the overall concepts and product architecture were determined.

Regarding the changes, that were given halfway through the study, only minimal differences between the groups were found in the later product. Some of the changes were easily incorporated into the old concept, while others caused fundamental changes, but there are hardly any differences between the two groups. Only one person (out of five) from the control group restarted with an all new concept after being informed about the requirement changes.

The time set forced everyone to solve the problem in the given time of 3 hours. 9 out of 10 of the participants finished “just in time”. Had there be no time limit or the task been much simpler, differences in design time might have been found.

The use of the following guidelines could not be found in any drawing or sketch: A.4 reduce internal cross linking/bus systems, A.5 reduce internal dependencies, B.2 oversize related to power, B.3 oversize related to strain, D.1 select technology, which is far form obsolete, D.5 plan „custom-features“ at the outside of the product, E.1 use parametric design.

On the other hand, following guidelines were used by many candidates of both groups: A.1 introduce/increase modularity, B.1 create buffer zones, C.2 use standardized parts, C.3 "freeze", F.2 aim for self adjusting designs.
The “freeze”-guideline (C.3) was used more often in the control group, although they had not been instructed. A possible explanation is that the members of the control group “automatically” stuck to their early concept, as many designers were observed to do [20], and that this had nothing to do with having a flexible design in mind. The experimental group used unambiguous (dis-)connecting devices (F.1) and planned additional functions (D.2), which could not be found in the control group.
The results of the evaluation of the questionnaire partly overlap with the findings from the analysis of the sketches, but partly show differences:
The experimental group created fewer concepts than the control group – one concept per person compared to two concepts per person –, but they spent more time in optimising the concepts to the given requirements. Some changes were easier to adapt than others, but no difference between the groups could be found.
There is also no difference in confidence in solving the design problem between both groups. Surprisingly the control group felt better prepared when the changes were presented than the experimental group. The experimental group participants felt more stressed (contrary to H5), when confronted with the new list of requirements, but were general less annoyed/ more relaxed compared to the control group throughout the process.
While all candidates were working on the problem for 3 hours (time limit) a wide range of estimated times (prior to the start of the exercise) can be found in the questionnaires, from one hour to one week, but this spread could be found in both groups.
Asked for the most negative experiences, most members of the control group mentioned the change of requirements. For the members of the experimental group this was hardly a point worth mentioning. This supports hypothesis H5, which states that using the guidelines keeps the motivation of the designers higher, when changes occur, but is contrary to the findings mentioned in the previous paragraph.
Although the guidelines were understood by all participants in the experimental group, only 1 out of 5 is of the opinion that the guidelines supported the work and made the work easier. All mentioned that it was hard to implement the guidelines. This is contrary to what was predicted in H4.
The experimental group would have liked to have more information about previous solutions of the design problem, while the participants in the control group were more or less satisfied with the given information. This can not only be found in the questionnaire, but is also supported by the number of questions asked during the test.

6 DISCUSSION

We proposed the idea of designing products with a flexible layout, which allows for easy adoption of new functions, when requirements are unknown at the beginning or change during product development. Some of the hypotheses could be supported and some of the research questions could be answered. The results, however, are still premature and further studies are necessary before the guidelines are evaluated such that the results support the introduction of the guidelines into the industrial product development context.
Surprisingly the candidates working with the guidelines felt less prepared when the changes were presented, than the group that worked without the guidelines. We have not found an explanation for that yet, but reasons might be that keeping the design flexible is like an additional requirement and restriction, which complicates the development process, so the students felt overextended. The students working with the guidelines created fewer concepts than the other group. This might mean that they did not think they needed another concept, as theirs was flexible, although it might also mean that due to the additional requirement, they had enough to do with one concept only..
Some guidelines were not used at all, while others were used by almost everyone in both groups (partly without knowing). At present we cannot distinguish between guidelines, that are more helpful, and others, that can hardly be implemented, because their use is probably highly affected by the given design problem and other context factors. Further research has to be done to determine if the idea of designing flexible products in a fast changing environment is a good approach to stay competitive and adapt easily to new requirements and handle uncertainties for all kind of products, or if the idea is limited to a specific area of product development and to a specific group of products.

Both evaluations showed some positive results using the guidelines, which possibly can be transferred to product development practice. The negative side effects are considered manageable. However, in the end the differences in working with and without the guidelines are small. This may be due to the fact that the comparative study was a laboratory study. Especially the effects of changes in the later phases (like production or after sales) of the product life cycle cannot be covered by the evaluations. These are the phases that are most affected by requirement changes and those later changes are most resource intensive (see Fig 2.).

Given the short time, the students were not very familiar with applying the guidelines. Furthermore, experience with the product to be developed (bioreactors) might lead to more positive results. Moreover, those guidelines, which appeared already in the education of the students are easier to use and easier to understand, e.g. modularisation, while we think that the idea of "freezing" in order to get a more flexible product is more difficult to understand.

7 CONCLUSION

Modern product development in fast changing environments needs a partly different approach than the classical process as described in literature, such as Pahl/Beitz [3] or Ulrich [13]. We therefore suggest a different approach, which concentrates on keeping the flexibility of the product under development. In order to design products with this specific focus, we collected and selected a set of guidelines, which should support the design engineers during the whole product development process.

These guidelines were evaluated in two different ways. While participant observation showed more or less subjective, but generally positive results, the results from the laboratory study are far less clear. Using the guidelines lead only to slightly better product designs than working without the guidelines. The hypotheses of being better prepared for changes, handling these changes and uncertainties faster and cheaper and keeping the motivation high, when using the guidelines could not be confirmed.

Thus more research has to be done to analyse if a flexible design is useful to handle the fast changing requirements and uncertainties. If so, guidelines can be used to support the development of such products. Our impression, however, is that they may have to be made more specific, and explained and practiced more intensively to lead to better results.

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