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DESIGN FOR MOBILITY - A METHODICAL APPROACH

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1. Introduction

People nowadays get much older and the proportion of old to young people is higher than ever before. Thus, it is crucial for the aging society, that aged people are able to live independently as long as possible, as there are not enough young people to assist them. Furthermore, independence is a precondition for quality of life. Most people feel that their quality of life suffers as soon as they are dependent on others. One essential aspect of independence is mobility [Mollenkopf 2001].

This contribution deals with the role of mobility in the design of products meeting the needs of aging users. Beginning with the role and understanding of the term mobility the need for research is derived from the challenges that occur in the development of mobility supporting products. A holistic view of mobility (described in section 2) exposes that integrating the users into the development process is one crucial aspect in developing mobility supporting products, but it is not enough. There are several requirements, which can be derived from user integration, but by describing the users more precisely and adding digital human models, many aspects can be considered much easier in the development process. The designers get a good overview over the users' needs and the influences on these needs and hence a better starting point for the application of user integration methods.

The contribution proposes the **concept for a methodical framework** that combines existing approaches for user integration, handling of variety and digital human modeling towards a holistic view on the design of mobility supporting products. This allows an optimal data exchange between the different methodical fields, as the data needed in later phases of the development process is known right from the beginning. How the elements of the framework have to be adapted to meet the special requirements of that field is separately described in the following sections for the methodical units of **capture of variant requirements**, **digital human models** and the **handling of variety**. In the end prospects are given for further research on realizing and evaluating this framework.

Although the framework aims at supporting the development of more innovative products in the future the authors come back to explain their ideas along the example of a walking frame (Figure 1) in this contribution for better illustration. Yet, even if walking frames are widely spread, their usability for most users can be improved.

2. Aspects of mobility

The importance of mobility for leading an independent life results from a holistic view of mobility. The most obvious aspect of mobility is the ability to move. But this is not sufficient. In order to be mobile in the sense of independence the abilities to communicate with other people, to transport things

like shopping and to interact with the environment are necessary as well. Only if none of these aspects is hindered, someone is mobile without restrictions.
Figure 2 illustrates the domains of mobility people typically move in. The inner circle represents home. This is a familiar area with a limited number of know barriers. Most people evolve strategies to overcome these barriers; hence they are mobile at home. The second domain is the familiar neighborhood, e.g. the way to the next shop, the doctor or friends. In this domain are more barriers than at home, but these are known as well and people know how to avoid them. The third domain is an unfamiliar area, like another city. Barriers in this area are unknown and it is hard to previously avoid them. They have to be overcome spontaneously. The last domain is not only an unfamiliar area, but culture and/ or language are unfamiliar as well. This makes it even harder to avoid barriers, as e.g. asking for alternative routes without stairs is more difficult. All capabilities needed at home are needed in the other domains as well, but with each domain additional capabilities are required.

Figure 1. Walking frame

Technical products to support mobility can be manifold. On the one hand there are many existing products from walking sticks or walking frames, which can be used in all domains, to stairlifts, which are installed on one particular staircase. But cars, airplanes and means of public transport are mobility supporting products as well. On the other hand there are innovative approaches like exoskeletons to support mobility or special products that support the users climbing stairs. The proposed framework is supposed for the second kind of products, but it will work for the first one as well.
The requirements for mobility supporting products depend on the users. There are the users' individual needs and habits that influence their expectations, how the product should work. And there are the users' competences and capabilities that influence the way they should be supported as well as their ability to handle the product.
As shown in Figure 2, in addition to the individual boundary conditions technical and social boundary conditions influence mobility. The technical boundary conditions are the availability of technical devices such as personal technical aids, a personal car or means of public transport. Social integration, infrastructure available and personal fears or the feeling of being safe, are social boundary conditions. All these boundary conditions are highly variable and individual. This and the fact that the users will use the product in the different domains of mobility, makes it impossible to develop one single product that is usable by all users in every situation. Thus, mobility supporting products have to be individual in order to fulfill the users' needs.
As it is impossible to develop individual products for every user, mobility supporting products have to be adaptable to the user and the use case. As the boundary conditions are variable, the products have to be adaptable in two different ways. First they have to be adjusted to the user's needs and capabilities, including e.g. body height and strength. During the use they have to be adapted to changing boundary conditions and the use in the different domains.
One crucial aspect in mobility supporting technology, as part of assistive technology, is that the support should be as much as needed but as few as possible. If physical limitations arise, it is helpful to train the remaining capabilities. Unlimited capabilities that are no longer used, because a technical system provides too much support, will get lost. Therefore, the product should be adaptable in three steps. The first one is to train, in order to avoid decreasing capability due to deficit of training. The

second step is to support people in using their capability and the last one is to compensate lost capabilities.

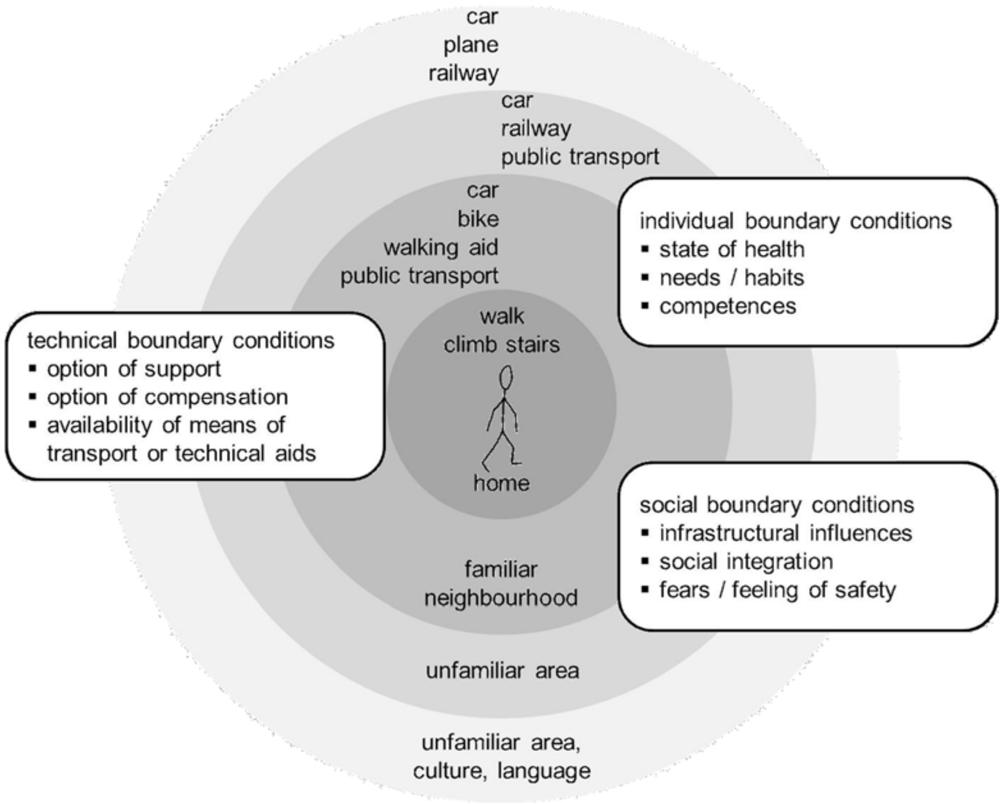

Figure 2. Domains of mobility based on [Lueth 2010]

Most of the existing technical products to support mobility are easy to handle in one of the domains, with one particular limitation, e.g. walking frames. This is not a particular problem with walking frames, but is the case for most mobility supporting products. As the framework in section 3 is described using the example of the walking frame, the problem with mobility supporting products is illustrated with the same example. The support of mobility in very special cases or domains of mobility can hinder mobility, as soon as it is necessary to move between the domains. Some people own more than one walking frame, one in the apartment, the other one for using outside, as it is impossible for them to bring the walking frame upstairs. Most of them are able to climb stairs, but not with the walking frame. Therefore, it is essential to develop products that are usable not only in one domain of mobility but in all of them and to move between these domains, unrestrictedly.

3. Framework for the development of mobility supporting products

The development of mobility supporting products involves particular challenges in product design concerning special characteristics of needs and requirements for those products. These challenges result from the analysis of mobility and the influences on mobility as described in Figure 2 as well as existing research [Huppert 2003] and interviews with users of walking frames.

The highly **individual** boundary conditions are described in section 2. As these boundary conditions can take shape in a very broad range and combination of boundary conditions they are not only highly individual to each user but also highly **variant over the range of users** [Huppert 2003]. Furthermore, they are not static in the life of each user so that they are even variant seen over the use phase of only one user [Huppert 2003] what is called **user-specific variant** in the following. As mobility includes even communication these needs often cannot be clearly expressed by the users themselves due to communication barriers. The needs are **implicit** and need to be identified. Interviews with 7 users of walking frames showed that it is very difficult for them to express problems in using the walking frame. Only if the problem was described by the interviewer and the users had to tell whether or not

they have had this problem themselves, they were able to answer this question. This implies that potential problems have to be foreseen, in order to get good results from interviews.
Especially elderly users often experience individual barriers in handling technical products so that acceptance can in many cases only be achieved if these individual, variant and implicit needs are fulfilled exactly. Figure 3 summarizes the specific characteristic of needs describing the development of mobility supporting products.
These individual, variant and implicit needs have to be understood and documented in order to develop the appropriate kind and range of products to achieve acceptance. Methodical support that helps designers to meet these specific constraints in the development of mobility supporting products shall be summarized under the term **design for mobility**.

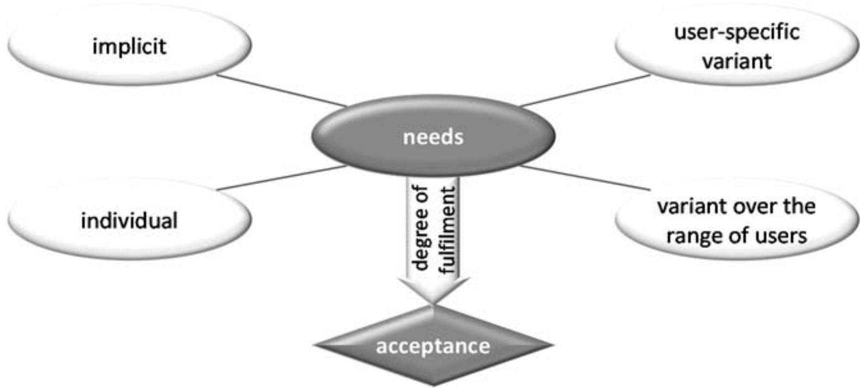

Figure 3. Specific characteristics of needs

Looking at literature different existing fields of design methods might partly serve the challenges of design for mobility. User integration and digital human modeling might support the capture, documentation and classification of implicit and individual user needs. Methods on the development of modular product families are established ways how to handle variety where the methodical framework for design for mobility can build upon. Although these fields of research offer basic methods how to meet single aspects of the special challenge in design for mobility (Section 4-6), they need to be adapted and put in relation to each other in order to offer a holistic support. Figure 4 illustrates a corresponding methodical framework.

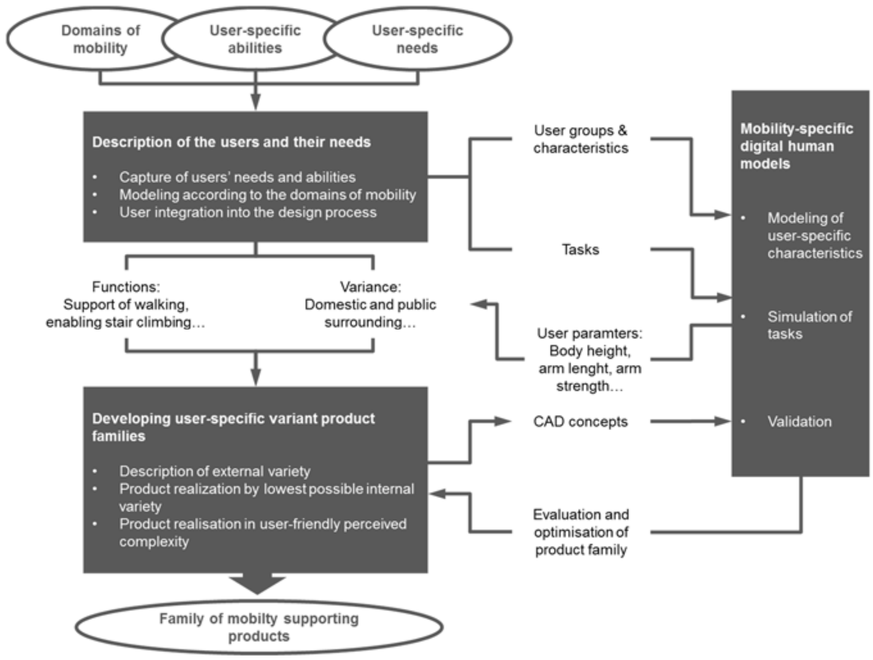

Figure 4. Methodical framework [Krüger 2011]

Basically, three method units are derived from the fields of research described above: description of the users and their needs, mobility-specific digital human modeling and development of user-specific variant product families.
The description of the users will provide user groups with similar characteristics as an input for the modeling. Hence, it is not necessary to build up a model for each user, but only for each group. Additionally, typical tasks that have to be fulfilled by the users in the different domains of mobility will be provided, in order to be able to simulate how well people from different groups perform these tasks. Beyond that, the functions that the product must have in order to fulfill the users' needs and expectations can be captured by the integration of the user into the design process. By example of the walking frame, necessary functions are e.g. the support of walking, enabling people to climb stairs with their walking frame or the possibility to transport shopping. These required functions and the knowledge about the variance needed are necessary for the development of user-specific variant product families. In the case of the walking frame, the variance could be the surrounding, either domestic or public or the possibility to have an additional navigation system.
The mobility-specific digital human modeling will provide user parameters, which influence the variance of the product as well. The CAD concepts of the products families can be validated with the digital human models and optimized, in order to get a family of mobility supporting products that is suitable for the majority of users and use cases.
A description of the methodical approach to get the output parameters as shown in Figure 4 can be found in section 4 for the description of the user, in section 5 for the digital human models and in section 6 for the product families.

4. Description of the users and their needs

Designing products which exactly fulfill the users' needs requires suitable knowledge of these needs. Methods of user integration are briefly described in section 4.1 and the need for further research in case of mobility supporting products in section 4.2.

4.1 State of the art in user integration

There are various methods for **user integration** in the design process. These methods can be divided in two forms of integration, representative or direct. Direct user integration means, that the user is directly involved in the design process. Methods for the active user integration are e.g. focus groups, where a group of potential users discusses a product idea in an early stage or tests, where users test prototypes of the product. Representative user integration means that the user is not directly involved in the development process, but represented e.g. by experts or simulation [Reinicke 2004].
The decision which method is the best one for the integration of users depends on various influences. On the one hand the aim of the user integration influences the method. Generating ideas for new products requires other methods than testing the products usability. On the other hand the data available and the sample have a strong influence whether a method is practicable or not or how it could be adapted. [Reinicke 2004].

4.2 Describing the users and their needs in case of design for mobility

In case of assistive technology it is impossible to design individual products for each user; even if these products would fulfill the user's needs best. Nevertheless, the better the product fulfills the user's needs, the higher will be the acceptance of the product and its usability for this particular user.
Hence, the users have to be known as well as possible. The users' needs result from the domain of mobility they are moving in and which borders between the domains they need to cross and how often. Additionally, the users' capability and the associated degree of assistance needed, influence the needs. To reduce the effort in getting the technical requirements for a mobility supporting product, one goal of this project is to develop a method to form groups of users with similar requirements. Therefore, one aim of further research is to find out which user-specific aspects influence the requirements of technical products and how strong these influences are. The loss of some capabilities is directly linked to particular illnesses [Paetzold 2009].

In order to simulate human capability typical tasks have to be identified. Only the link between the capability of the users and the tasks they perform can provide information whether or not assistive technology is needed. In case of the walking frame, a typical task is crossing a street. This includes going down from the pavement to the road, crossing it and climbing the curbstone on the other side. In addition to the ability to walk, it is necessary to be able to get the walking frame up and down the curbstone. This activity might be simulated with different user-specific parameters such as body height or strength and in a second step with different CAD concepts of the product in order to find the best concept concerning this task. Hence, a method to get the typical tasks has to be found.

Another aspect of the development of mobility supporting products is to derive product functions from the user description. As the users are a heterogeneous group with specific needs, as shown in Figure 3, the product functionality has to be variable and adaptable. Variable means, that there is more than one possibility to fulfill one function, according to the user's needs at the beginning of the time of use. Therefore, the range of variance has to be defined. One variable parameter for the walking frame is the user's body height. One possibility to cope with this variance is to design one product, which can be adjusted to all body heights. The second possibility is to design the product in different sizes, so that the range where it has to be adjusted is much smaller.

Even if the product is adjusted to the user's needs, it has to be adaptable to the changes of the user's capability due to the aging process and/or illness. As described in section 2 it should provide as much support as needed but as few as possible. Some functions might be added with arising illness, others become unnecessary. And the product has to be adaptable to different use cases. Use cases for walking frames are inter alia defined by the domain of mobility someone is moving in. In the apartment a walking frame should be as agile as possible, whereas on a cobbled surface it is important to minimize vibrations. There are walking frames available with two sets of wheels that can be changed easily; one for smooth and one for rough surfaces. But the wheels have to be changed manually, so it is assumed, that they are not changed every time it would be useful. The idea is to provide products that automatically adapt to the different use cases, either triggered by the user or fully automatic.

There are methods to capture the users' needs and abilities from social science as well as methods for the integration of users. These methods have to be combined in a way that the results are suitable for both mobility-specific digital human modeling and the development of user-specific variant product families.

5. Digital human models in design for mobility

Design for mobility is characterized by special challenges concerning user integration and management of variety. On the one hand the abilities and needs of the user are not always explicitly known on the other hand they are subject of strong variance which makes a statistical point of view advisable in many cases.

Digital human models can help to encounter these challenges by conveying information to an objective, data driven and, therefore, engineering-like point of view. The basic idea is to create a digital **mobility-specific model** of the user taking into account as many user-related characteristics as available such as age, gender, degree and type of impairments etc. Afterwards the abilities of the user to carry out typical tasks are simulated. Depending on the level of abstraction these simulations can serve to derive initial product requirements or to validate existing concepts. In this way a representative user-integration into the design process is achieved which allows the designer to dispense with time-consuming activities like usability tests or surveys.

5.1 State of the art in digital human modeling

The term **digital human model** comprises computer-aided methodologies that aim at the representation and simulation of human properties and behavior. The corresponding research area originates from the human factor sciences where digital patterns were used quite early to represent body dimensions (anthropometric measures) within ergonomic case studies. Today one can distinguish several domains of digital human modeling, each of which deals with a certain human aspect. Since design for mobility primarily deals with the user's ability to move, only **biomechanical models** are addressed in this paper. **Biomechanical models** focus on the musculoskeletal system consisting of bones, joints and muscles which is modeled as an overconstrained multibody system. Based on a given motion sequence and forces externally imposed to the body it is possible to determine the resulting internal effort that is necessary to carry out the specified motion. Common measures are joint torques and reaction forces, muscle activity, and overall mechanical work [Delp 2007]. In design, Rasmussen et al. [Rasmussen 2003] proposed biomechanical modeling as a method to address ergonomic problems. A musculoskeletal model of the upper body was used to obtain an optimized design of a hand saw. In the field of assistive technology Medland and Gooch [Medland 2010] employed a digital mannequin to estimate body poses of paraplegic persons in order to improve the design of wheelchairs.

5.2 Application of digital human models in design for mobility

The integration of digital human modeling into the methodical framework shall be discussed within a hypothetical case study. The product to be developed is a walking frame which is widely used by persons with impairments concerning the ability to move in a secure way.

Following a user-centered design approach, the prospective users of the walking frame have to be analyzed in a first step. Methods for the description of the users and their needs (Section 4) are employed in order to form groups of users with similar characteristics. For the walking frame relevant user-characteristics are age, gender as well as type and degree of impairment. Moreover, these methods will provide information about the task the user wants to accomplish using the product. Turning towards the present example, a typical task would be crossing a street with a walking frame which is regarded problematic by many users since the curbstones have to be surmounted. This task involves the musculoskeletal system in the first place. Hence, a biomechanical human model can be used to simulate the interaction between the user and the product (Figure 5). In order to cover the characteristics of the considered user group, the model has to be **non-ideal** or in other words **mobility-specific**. This means that not only the body dimensions but also physiological properties like muscle strength, ranges of joint angles and so on have to be treated like variant quantities that may underlay a certain statistical distribution. Accordingly, the simulation results are statistically distributed as well. In this way, the effect of physical impairments on the feasibility of the task can be taken into account.

The simulation can provide two types of information depending on the level of detail. In early design phases it is possible to omit the model of the product and focus solely on the human itself. In this case the simulation result consists of user related parameters e.g. length of limbs or maximal achievable hand forces. This information can be used to derive initial product requirements. In subsequent phases of the development process as soon as geometrical concepts are available, the product is included into the simulation model. This allows an examination of the whole system formed by the user and the product for the purpose of concept evaluation and optimization.

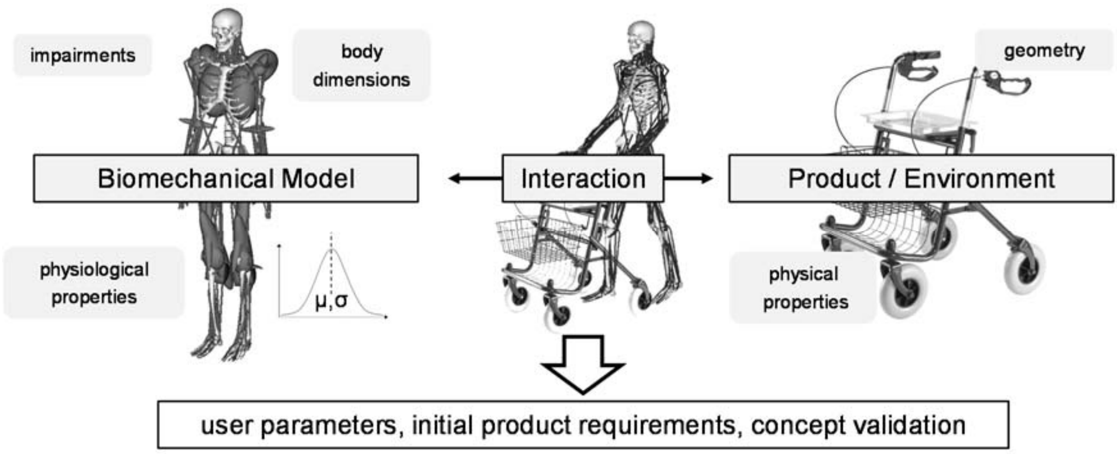

Figure 5. Biomechanical simulation

To turn this hypothetical case study into reality further research is needed. Today in general biomechanical models like OpenSim [Delp 2007] do not allow a task-based description of the simulation. Instead the task to be simulated has to be defined on a low level of abstraction. This means e.g. that motion sequences that occur during the task execution have to be recorded from real test persons. Because a recorded motion only applies for a single test person (the one in front of the recording system), a different approach has to be chosen to cover a huge variety of users. The algorithmic planning of human motions is regarded a promising approach. Another unsolved challenge is the integration of statistical distributed user-characteristics such as physical impairments into digital human models. Further research will have to address these questions.

6. Handling user-specific variety

Analysis of user needs showed that the needs vary over the range of users and during the use of one user. Furthermore, these needs need to be met very precisely in order to achieve product acceptance (section 2). For this reason methods that might be suitable for handling variety within design for mobility are described in section 6.1. Implications for further research are derived in section 6.2 and outlined on behalf of the example of a walking frame.

6.1 State of the art in methods for handling variant user needs

Various methods have established which support in developing products that fulfill a broad range of customer needs. These methods have been collected in a state-of-the-art review by Jiao, Simpson and Siddique in [Jiao 2007]. Furthermore, the integrated PKT-approach for developing modular product families was subsequently presented in 2010 developing and combining single methodical units for specific aspects in product family design [Krause 2011].

One concept that particularly concentrates on the question how individual and variant customer needs can be met exactly is the concept of Mass Customization [Pine 2008]. Pine emphasizes the difference between offering several variants to make the user choose the one that comes his needs the closest and offering the user a product that is individually customized to his or her specific needs. Yet, in order to develop mass customized products he refers to methods for developing modularization and platform design what are the main aspects of the approaches on product family design named above.

While developing products that meet individual and variant customer needs can be supported by approaches on product family design and mass customization, the fulfillment of user-specific variant needs cannot be covered by the analyzed approaches. Regarding design for mobility requirements on further research can be derived concerning the handling of variant user needs:

1. Development of an approach suitable for the development of products that cover user-specific variant needs
2. Combination with existing approaches supporting the development of products that cover individual needs being variant over the range of users
3. Integration within a methodical framework on design for mobility.

6.2 Implications for developing user-specific variant product families

A methodical unit covering the three requirements described above leads to the development of product families by reducing variety in two dimensions. The first dimension is known from Mass Customization as well as approaches for product family design: reducing internal technical variety within a company by yet offering a broad range of products in order to fulfill individual, variant customer needs. In the second dimension the point of view is changed. In the first dimension variety is seen from the point of view of a company serving a range of users. In the second dimension the point of view of the user himself is regarded. The user experiences a change of abilities for example due to age-related decreasing physical abilities or due to increasing physical abilities by training. As for mobility supporting products it is crucial to support as much as needed but as less as possible the product needs to fit to the individual and temporally variant user abilities at any time. Furthermore, the boundary conditions change daily for example if the user changes from moving within the own apartment to moving within city traffic. Today this variance the user experiences is either covered by different products or not fully covered as existing products bring trade-offs for one or the other situation. The aim of developing user specific variant products is to cover variant needs by one individual flexible product. A product family covering both dimensions of variety is called a user-specific product family in the following. Figure 6 demonstrates these dimensions within the model being used for the integrated PKT-approach on developing modular product families [Krause 2011].

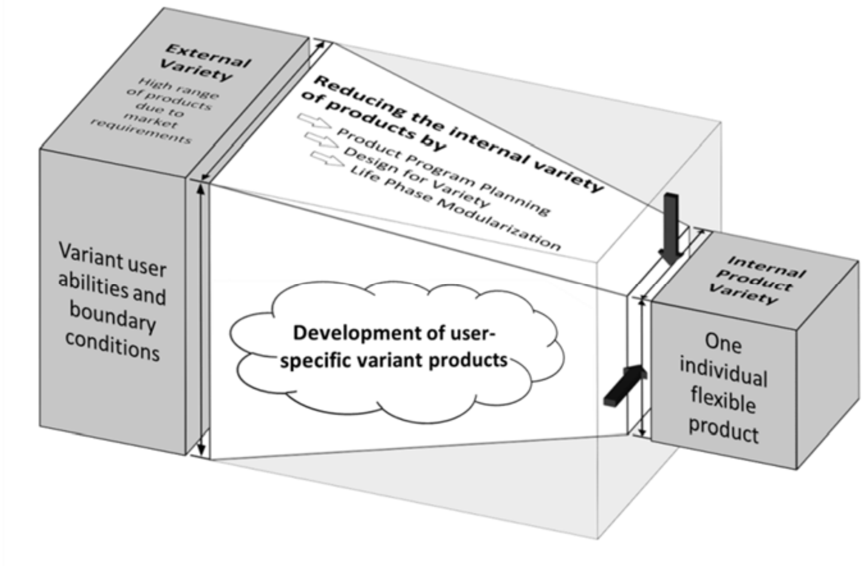

Figure 6. Two dimensions of variety in the development of user-specific product families

As the viewpoint of the user himself on the variety of his or her product is only described rarely within literature this aspect is outlined in the following by example of a walking frame. A user-specific variant product as demonstrated in Figure 7 might be configured in a way that there are interchangeable modules that allow best support in all cases of use for example by changing when the user is changing between mobility levels e.g. from his own apartment to public infrastructure. The advantage would be that e.g. the chassis module for use at home could be optimized in terms of agility in small rooms and the variant for traffic use could be optimized for climbing curbstone or damping rough underground. Furthermore, the product could have flexible modules that adjust to changing physical conditions as the body height or needed support for the arms. Reduced orientation skills could be supported by a navigation system. The part of the product being in contact with the body could be customized to the individual body in order to offer best ergonomic conditions e.g. individually fit handles and handle bars adapted to girth and arm length. As this individually customized module forms even the basis of the product in any use case it can be seen as a kind of platform from the users point of view being configured for each use case. In order to achieve user acceptance the configuration of the product needs to happen ideally without additional efforts of the user. In order to realize this appropriate design of interfaces is needed.

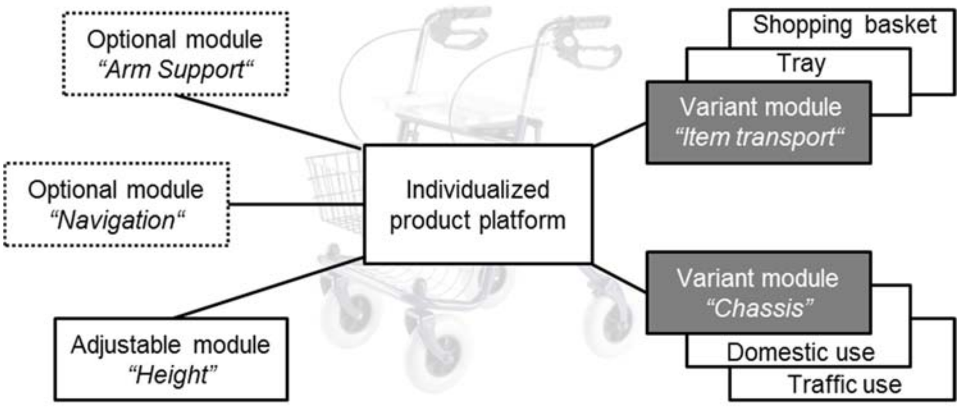

Figure 7. Example for configuration of a user-specific variant walking frame

7. Conclusion and outlook

This contribution describes a framework for a holistic approach for the development of mobility supporting products. First of all, the users are described and clustered and typical tasks are derived. Additionally, the functions and their ranges are defined. By modeling the user-specific characteristics and the simulation of the tasks, additional information for defining the variance is provided. Using the information provided by the first two steps, a user-specific variant product family is developed. The CAD concepts are validated through simulation and optimized. The result is a family of mobility supporting products.

The aim of this project is to combine known methods to a holistic approach. As the methods are adjusted to each other, the input and output parameters provide the data necessary for the next step.

Further research is needed in all three sub-projects, to find the appropriate methods and the optimum combination of methods.

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