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# Platform of Design Method for developing mobility-preserving products

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## Abstract

Preserving the mobility of elderly people is becoming increasingly important, as other factors of quality of life, such as autonomy or participation in social life, are connected with mobility. Starting from an analysis of elderly people as users, combined with the analysis of mobility and mobility situations, a catalog of functions is presented in this paper, which provides the basis for a methods platform to develop user adapted modular mobility-supporting systems.

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## 1. Introduction

Preserving the mobility of elderly people is becoming increasingly important, as other factors of quality of life, such as autonomy or participation in social life, are connected with mobility. Products that preserve the mobility of elderly people can therefore significantly improve their independence and quality of life. Based on the changes in the age structure of society, demographic change also means to increasingly utilize available support by technical systems to allow people a self-dependent and self-determined lifestyle.

In this context, the focus of considerations related to mobility support by technical systems are elderly people respectively people with performance restrictions. Not only because of the variety in the occurrence of performance restrictions but also by the diversity of biographies (social integration, career, life experiences), elderly people are a very heterogeneous group with diversified needs and requirements for technical systems.

Diverse mobility situations require flexible concepts that need adjustments based on different aspects. The basis of

considerations is the adaptation of products to the individual performance of the users. Elderly people partly have very individual barriers in handling technical systems as well as in the use of public and private spaces. Unsecurity and fear of handling technical systems have to be taken seriously as well as aspects of stigmatization to ensure the acceptability of the product. The user does not want and should not be necessarily confronted with the entire complexity of technical systems. In parallel, any forms of barriers in the use of technical aids have to be avoided.

A holistic approach to mobility does not only conduce to great potential for innovation for mobility support. The challenge for product development is also to consider the variety of influencing factors that determine the requirements for mobility-aided systems and the associated possibilities for finding solutions.

A number of studies show that elderly people are pedestrians especially in the immediate home environment [1]. In the case of driving is no longer possible there is a preferred change to public transport, which is also connected with the fact that more routes must be done on foot; in this

context, the walk to stopping points or the interchange with other modes of public transport can be mentioned. Other important aspects are the need to manage differences in altitude, such as climbing stairs or to get on or off a bus, which have great significance in terms of mobility. Generally, conventional mobility solutions support these functions (walking frame, stairlift) only partially.

For the derivation of technical aids for mobility support a holistic mobility approach is required that reflects not only the mobility situation but also considers individual conditions and social factors as well as the characteristics of public and private space more closely. Based on this a mobility model will be shown, how innovative product ideas can be derived for targeted support.

To implement the product ideas in mobility aided product families requires methodological support to ensure a user centering within the development and thus the acceptance and related efficiency of developments. This consists of three main topics:

- The methodological development of mobility aided product families requires a consideration of the analyzed situations of mobility when requirements will be formulated. It is necessary to recognize desires and needs of the user in terms of his mobility by taking into account individual performances. From the description of mobility situations functions will be derived, which concretize the needs of the user as well as the description of the situation. In summary the complex behaviorally based construct of acceptance may be explained. With these factors, the requirements related to the product family can be completed in terms of acceptance and concomitantly deliver reference criteria for the product family to ensure a process attendant property validation.
- To enable an efficient product development process, the ability for a continuous computer-aided validation of product properties, capabilities and needs of the users should be provided by digital human models. The objective of the project is to extend the biomechanical human model in order to consider elements of mobility-related performance restrictions. Furthermore, this procedure, a native of sports medicine, has to be adapted in some points to be reasonably useful for product development and development process.
- Due to the variety of mobility situations described above the development of variant-adapted, modular product structures is required. In addition, the product concept has to realize a huge spread of capabilities and needs not only with respect to different users but also during the utilization phase of one individual user related to their changing mobility grade. Here, the advantages of modular product structures are methodically extended by variable user requirements during the life-phase “product use”. Within the project, a specific methodology for a mobility-oriented modularization will be developed based on Integrated PKT-approach of the development of modular product families exemplarily shown in [18].

## 2. Dimensions of a User Description

Technical systems can support elderly people in their mobility because with this aid the restricted functionality in motoric, sensory and cognitive abilities may be compensated. Basically for supporting technical systems are descriptions of the functionality which has to be compensated respectively supplemented.

From a medical and gerontological perspective, it is useful to observe a progression in the support. In principle, people in old age may not be restricted in their freedom of action by using products. In fact it is necessary to delay the progression of the loss of abilities so that the own capabilities and the joy of life connected with this will remain as long as possible (avoidance of *circulus vitiosus*). For this purpose a hierarchy for support was derived, which allows the designer to define a degree of support [2]:

- **Motivation (animation and training):** First, the technical system should only stimulate the users to use it to facilitate daily routines. The aim of the product must be to strengthen the own capabilities. It is also essential to design the product attractively so that the user enjoys it in his everyday life.
- **Support:** Second, the technical system has to assist in the use of existing capabilities in difficult situations by using available capabilities. The aim is now to receive the leftover capabilities as long as possible respectively to train compensative capabilities.
- **Compensation:** Third, only when capabilities are not (or not more) sufficiently available, these should be compensated by the technical system completely, to continue to ensure independent living in the familiar environment. As products for the compensation are necessary to conserve an autonomous lifestyle, the aspect of functionality becomes more important for the user.

In the past, it turned out many times, conservative products for elderly people, but the acceptance of these products was not guaranteed. Within the meaning of an effective product development an advanced requirement description is required, which does not only consider functional aspects based on the user-behaviour and the user’s performance restrictions, but also the user’s intention and his motivation for the product-use. Here it seems to be helpful to analyse the user’s point of view at the product and his interpretation of the product. The different perspectives of developers and users to the product have to be considered as well.

The development of a product follows the principle of finality, based on the system’s purpose technical solutions will be developed and specified. However the user interprets the product corresponding to the principle of causality. The product will be perceived as an isolated object, which will be interpreted with regard to the content. Hence, the user concludes the system’s purpose [3]. In the course of interpretation the users evaluate for themselves, whether an expected system-purpose is fully achieved (effectivity) and how the effort-benefit-ratio will be in this context (efficiency). From this evaluation an attitude to the product results which

describes the satisfaction of the user with it. This definition correlates with the definition of usability [5]. Here, two aspects are required:

- The description of the purpose of a product is the prerequisite for the usability as well as the development process. The development engineer’s purpose may be distinguished from the user’s purpose.
- Aspects of the „Joy of Use“, a statement concerning the user’s pleasure, autonomy and performance when using the product are not included here.

Considering the explained hierarchy of support, it becomes apparent that even in terms of motivation and training the focus on a pure functional view is not enough. The emotional value, the image value and the perceived value of the user play a major role as well [4].

The values described are very subjective factors, which are influenced by social, cultural and individual characteristics of the user. It is proven critical to measure these factors as well as to derive concrete specifications for product development from them. To rate the importance of factors it is required to explain the context and to concretize the conditions of use. Therefore, it is necessary to specify this mobility situation more accurately.

**3. A description of the mobility-model**

In the contemporary context, mobility is interpreted as the possibility to move in private and public areas. Approaches for technical support concerning mobility highlight the physical aspect of motion in the environment. The agility and mobility of elderly people is also affected by their possibility to communicate and to interact with their social environment in order to participate in public life and to gain recognition. The possibility of mobility is for every individual person connected with personal autonomy and freedom.

A holistic approach to mobility offers great potential for innovation concerning mobility support. The challenge for product development is also to consider the variety of factors that determine the requirements as well as the possibilities for finding solutions. Therefore, a design method requires the detailed analysis and description of mobility situations.

First situations of mobility shall be classified in so-called mobility-circle (figure 1). The basis for such a classification is established in gerontological models for mobility [6]. Several theories describe that elderly people restrict their activity radius based on the increasing loss of the own mobility capacities and the associated increase of incertitude. Because of this safety needs are the reasons for this reaction [7].

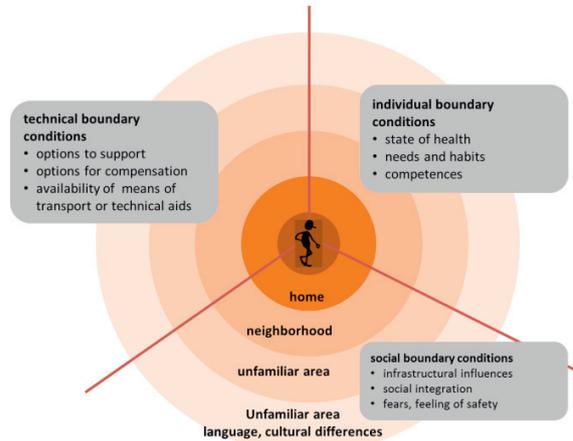


Figure 1: Basic model to describe mobility situations [11]

Second typical activities within the mobility circle are detailed and analyzed. A hierarchy of activities in the circle “flat” is exemplarily shown in table 1. By analyzing basic activities, certain recurring patterns can be identified. Such patterns are, for example, *to get up* as initiation of any mobile action, *to walk* as a basic movement, *to overcome altitude differences* in walking (stairs, kerb stones, ...).

Table 1: Part of hierarchy of activities in the circle home + leads to upper levels

<p><b>personal hygiene</b></p> <p><b>wash body (bath, shower)</b></p> <p>get in/get out (with altitude) +</p> <p>stabilise body +</p> <p>grab objects+</p> <p>use objects</p> <p>move arms</p> <p>execute forces by arms</p> <p>move fingers</p> <p>execute forces by fingers</p> <p>...</p> <p>move upper body +</p> <p>bend down upper body+</p> <p>...</p> <p><b>wash upper part of body+</b></p> <p><b>use toilette+</b></p> <p>...</p>
<p><b>cleaning the rooms</b></p> <p><b>stand up</b></p> <p><b>move legs+</b></p> <p><b>move objects</b></p> <p><b>balance objects+</b></p> <p><b>move objects with forces+</b></p> <p>move arms</p> <p>execute forces by arms</p> <p>move fingers</p> <p>execute forces by fingers</p> <p>...</p> <p><b>move arms (over head) +</b></p> <p><b>move upper part of body+</b></p> <p><b>hold balance+</b></p> <p><b>transport objects+</b></p> <p>...</p>
<p><b>supplying +</b></p> <p><b>pursue hobbies+</b></p>

Based on these basic activities, functions which have to be supported may be derived in terms of a catalogue of function for mobility-support. Considering that these functions are necessary in several mobility-circles, it is important in the use of the catalogue to create approaches which support a circle-comprehensive thinking respectively a function-comprehensive thinking. To illustrate this aspect, the *function to overcome altitude differences* is explained: altitude differences result from stairs as well as when getting on or off a bus. Both activities are important in terms of mobility and are normally coupled with the functionality *walk*. Conventional mobility concepts normally support only within one mobility circle or only one function (lift for stairs, walking frame). Often in fulfilling the other functions, the product has to be seen as a barrier. Therefore it is the thinking in complete scenarios for mobility with a lot of functions necessary. One solution approach for supporting these coupled functions could be a partial exoskeleton for lower extremities.

In a next step, it is necessary to have a closer look at the capacities of elderly people. For this purpose, existing catalogues were used, which explain and structure typical performance restrictions of aging [12, 13, 16]. With the help of these descriptions, the catalogue of functions for mobility support will be completed, namely when performance restrictions have to be supported or to be compensated by additional functions (see chapter 2, hierarchy of support). In addition, ranges of values for parameters of the listed functions that complement the requirement description for product families can be derived from the typical performance restrictions.

Existing examples showed that the acceptance of mobility-supporting products is not only determined by the pure technical functionality but also by aspects of the social and cultural integration of the elderly, their education, experiences etc. The consideration of these “soft” factors is essential to ensure the economic success of product innovations in the field of mobility.

To understand the motivation for a more or less active participation in the life is extremely difficult, because there are a lot of factors to consider, which may have a number of different characteristics. First approaches to describe these influencing factors were derived from a study of socio-scientific and gerontological literature. Principal model approaches which are considered are several mobility models and terms of age as well as social approaches of gerontology [for example 6, 8, 9, 10]. Initial findings which describe the use of technical systems in mobility situations are summarised in table 2. This summary has to be completed and concretised by further research activities and by using socio-scientific methods.

Finally, the detailed description of soft influencing factors of mobility situations and their possible characteristics will be used to classify the user. This classification is the basis for describing specific user groups which is used to complete the catalogue of functions for mobility support as well as to select and to structure principle solutions to support the modularisation for the generation of variants.

Table 2: Aspects of mobility and their characteristics

<p><b>degree of support</b></p> <ul style="list-style-type: none"> <li>based on physical capabilities               <ul style="list-style-type: none"> <li>degree of mobility is describable</li> <li>defines the objective circle of mobility</li> </ul> </li> <li>awareness for the own life-situation</li> <li>degree of one's own initiative</li> </ul>
<p><b>motive for mobility</b></p> <ul style="list-style-type: none"> <li>mobility as purpose               <ul style="list-style-type: none"> <li>technical system as an instrument to fulfil needs</li> </ul> </li> <li>mobility that end in itself               <ul style="list-style-type: none"> <li>to preserve autonomy</li> <li>awareness of the life-situation</li> </ul> </li> </ul>
<p><b>type of support</b></p> <ul style="list-style-type: none"> <li>corresponding to daily life</li> <li>acceptance of use</li> <li>outlying of daily life               <ul style="list-style-type: none"> <li>effort-benefit-estimation</li> <li>joy of use</li> <li>safety in use</li> </ul> </li> </ul>
<p><b>barriers</b></p> <ul style="list-style-type: none"> <li>concretely existing               <ul style="list-style-type: none"> <li>in case of performance restrictions</li> <li>resulting from the arrangement of public and private areas</li> </ul> </li> <li>subjective perceived               <ul style="list-style-type: none"> <li>interpretation of technique</li> <li>open mindedness for technique</li> </ul> </li> </ul>

#### 4. Enhancement of a platform of methods for mobility support

Based on the detailed description of mobility-situations and elderly people as users, a holistic approach for the development process is required, which includes design methods for the validation of properties concomitantly to the development process as well as methods for the definition of the variants and their modular product structure. The special challenge for a methodical support is on the one hand the high heterogeneity of the elderly people as users for personalized products and on the other hand the high effort of the development of modular product structures to fulfil all the individual requirements. These approaches are introduced in the following chapters.

##### 4.1. Digital human models for the property validation

To enable an efficient product development process, digital human models shall provide a possibility for the continuous computer-aided validation of product properties in relation to properties, capabilities and needs of the user. One aim of the developed approaches is the extension of a biomechanical human model in order to consider elements of mobility-related performance restrictions. Furthermore, the simulation procedure sports medicine must be adapted for the application in product development and usefully integrated into the development process.

Basis for these considerations is the requirement specification using the function catalogue for mobility support. For product developers it is important, that these requirements are quantifiable as accurately as possible and, thus, objectively verifiable. However, the quantification is

often only possible depending on the characteristics of the user's body. In the case of a partial exoskeleton “knee”, this, for example, relates to the required degree of support, whereas the required force effect to realize a relief of the musculoskeletal system may be highly dependent on the body weight, size and the existing performance restrictions [14, 17].

To avoid time-consuming and for the test person stressful laboratory studies, biomechanical simulation models are developed, which contain all relevant user characteristics. That way, the product developer gets a tool that enables him to predict the impact of his decisions on the musculoskeletal system. This, in turn, allows him to quantify the required relationship between the requirements and technical parameters without being already bound to a particular solution concept.

The formulation of the user properties within the model must be done stochastically, so that the variance of the inherent problem can be simultaneously quantified. Since this is based on existing simulation technologies, it is particularly necessary to integrate performance restrictions in the simulation model and to develop motion synthesis programs for typical mobility tasks (e.g. standing up, climbing stairs, etc.). In addition, the most significant output quantities of all possible values have to be identified and validated experimentally.

#### 4.2. Modularization concept for product families

The variety of mobility situations on the one hand and the changing capabilities and characteristics of the users on the other hand are the two main challenges for the product development. In addition to the huge spread of variant requirements derived from different individual users, there are variable requirements derived from one user with its changing mobility capabilities during the use of the product, which must be considered during the design process. For this the advantage of modular product structures in dealing with a high customer-driven variety is methodically extended with the idea of variable user needs during the utilization phase. An adapted method based on the Integrated PKT-Approach of the development of modular product families will be developed [15, 18]; exemplarily shown in [17].

The requirements collected in the function catalog for mobility support and derived value ranges from it are the basis for the derivation of product variants to produce and variable product features to adapt during product use. Here it is to identify which values vary across all users for the product variants and to derive a corresponding variant range. Furthermore, it must be analyzed which of these values are also variable over the whole utilization phase of one user including the correspondent ranges of values. These required product variants concerning all users and the variability in the utilization phase of one user have an influence each other. This is a new challenge for the development of design methods, which develop modular product structures. Current methods for visualizing the required external product variety, such as the tree of external variety, do not support this multidimensional description of variance and variability [15, 18]. Regarding variability during product use methodical

design of interfaces gets even more important and needs to be advanced in research. The usability of interfaces the user, the physiotherapist or medical doctor will have to use to adjust the product to actual mobility and capability situations becomes extremely important to ensure product acceptance. First published approaches [17] to address these problems are continuously being further developed.

## 5. Conclusion

Elderly people partly have individual barriers in handling technical systems as well as in the use of public and private spaces. Uncertainty and fear of handling technical systems have to be taken seriously as well as aspects of stigmatization to ensure the acceptability of the product. The user does not want and should not be necessarily confronted with the entire complexity of technical systems. Any forms of barriers in the use of technical aids have to be avoided. Elderly people need a sustainable support by technical systems. The support should be available so far as it is necessary to obtain or to train the performance. Only when this is no longer sufficient to satisfy mobility needs, the technical system should compensate the lost performance (support hierarchy).

For the derivation of technical aids a holistic mobility model is required that reflects not only the mobility situation but also considers individual conditions and social factors as well as the characteristics of public and private space more closely.

The methodological development of product lines requires an implementation of the analyzed situations of mobility into concrete requirements. With these factors, the requirements related to the product line can be completed in terms of acceptance and concomitantly deliver reference criteria to ensure a process attendant property validation. The ability for a continuous computer-aided validation of product properties, capabilities and needs of the users should be provided by digital human models.

The variety of mobility situations requires the development of variant-compliant, modular product lines. In addition, the products must meet a huge spread of capabilities and needs not only with respect to different users but also during the utilization phase of the individual user. The advantage of modular product lines to manage a high customer-driven variance is methodically extended by the life phase “product use” including the additional varying user requirements. Within the project, a specific methodology for a mobility-oriented modularization will be developed and exemplarily shown.

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