SUPPORTING INCLUSIVE PRODUCT DESIGN WITH VIRTUAL USER MODELS AT THE EARLY STAGES OF PRODUCT DEVELOPMENT

Pierre T. Kirisci[1], Klaus-Dieter-Thoben[1], Patrick Klein[1], Markus Modzelewski[2]
(1) BIK - Institut für Integrierte Produktentwicklung (2) TZI - Technologie-Zentrum Informatik und Informationstechnik

ABSTRACT
The aim of inclusive product design is to successfully integrate human factors in the product development process with the intention of making products accessible for the largest possible group of users. In order to meet the challenge of inclusive product design, the involvement of human users in all phases of the development process has so far been an efficient approach. Yet, such ergonomics evaluation experiments that employ a versatility of user groups are not only complex, but can be very time and cost-intensive. Therefore virtual user models (VUM) have been proposed for supporting certain phases of the product development process. The aim of this paper is to explore how virtual user models and associated design approaches can be used for inclusive product design and to conceptualize user interfaces of consumer products in such a way that even the needs of users with physical impairments are fully considered. Supported by this challenge, a model-based design approach is proposed and conceptually elaborated, which supports inclusive design of consumer products particularly at the early stages of product development.

Keywords: Inclusive Product Design, Virtual User Models, Product Development, Model-Based Design Approaches

1 INTRODUCTION

Inclusive design is a process that results in inclusive products or environments which can be used by everyone regardless of age, gender or disability [1]. The main barriers for adopting inclusive product design include technical complexity, lack of time, lack of knowledge and techniques, and lack of guidelines [2]. Although manufacturers of consumer products are meanwhile less reluctant to invest efforts in user experiments, consumer products nevertheless conditionally fulfill the accessibility requirements of users [3]. The reason is that product tests with users are usually done at a rather late stage of the product development process. Thus, the more progressed a product design has evolved - the more time-consuming and costly is an adaptation of the product design. Evaluating alternatives from an accessibility standpoint, when it is still relative inexpensive to change the design, can improve the accessibility features of the product [4]. As a consequence, there is a substantial demand for methods and tools which are capable of credibly replacing experiments with human users in the early product development phases. The early product development phase can generally be referred to as the “conceptual design phase” which includes phases such as sketch, design and evaluation. Designers therefore need support by simulating the interface between users and a consumer product from the earliest stages of the design and engineering processes. One promising practice for realizing inclusive product design is to employ virtual user models (VUM). Virtual user models have the potential of complementing tests with real users in the early design stages, while a VUM can be seen as an abstract representation of the simulated behavior a human user. Virtual User Models are three-dimensional, model-like images of reality and usually contain the following functions: (1) Human body modeling and analysis (2) Animation of virtual users (3) Interaction of virtual users with virtual objects. [5]. Nowadays virtual user models are utilized for ergonomic analysis in vehicle and workplace design within the automotive or aerospace industry. They are used to validate the design in a simulation environment, check in a loop if the design is suitable, refine it considering recommendations and best practices and finally, when found suitable produce a prototype to be checked by end users as shown in

Fig. 1. More rarely are virtual user models applied in the evaluation of consumer product designs and even less for usability and accessibility of consumer product’s interfaces, although having similar objectives for inclusive design processes. For the sketch phase static models of the user are applied, while during the design phase virtual user models of humans can have the notion of three-dimensional human models, in most cases incorporated as an additional functionality or as a Plugin of a CAD application. Despite the different approaches which involve virtual user models, only the approaches based on anthropometrical data are suitable for serious simulation and can meet the ambitious goals of the accessibility evaluation of user interfaces of consumer products at the early stage of the development process. However, there is neither a standardized framework, nor a common understanding in literature, how specific user features can be sufficiently represented virtually [4]. As such the usage of virtual user models for a continuous support of sketch, design and evaluation phases can therefore be considered as unique. Thus, contemporary approaches where virtual user models are utilized are only partially suitable for inclusive design. With respect to this background it is of particular interest to explore how virtual user models are capable of complementing the involvement of real users within the early product development phases.

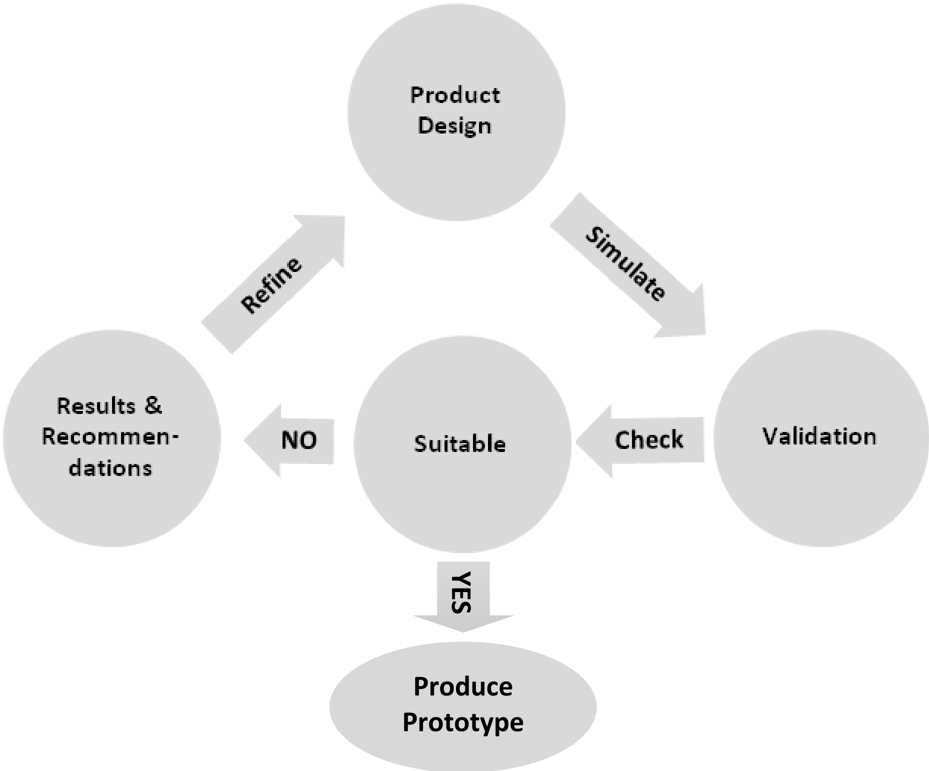

Fig. 1: The process of validating and refining designs with Virtual user Models [5]

2 RELATED WORK IN VIRTUAL USER MODELS

The first attempts to develop virtual user models began in the 1960’s when the digitization of two-dimensional anthropometric models became available. In the early years and decades many research groups from industry as well from universities followed their own proprietary approaches, because the costs of the realization of such models were comparatively low. The concepts ranged from a representation of a human as simple composition polygonal main body of the modeling from many horizontal layers up to the representation of a variety of stapled balls. Further developments were mostly driven by specific requirements from the industry. The majority of these models were mainly developed for the areas of aerospace and design of airplanes, where training and experiments on real tasks were mostly expensive or impossible; therefore they had to be simulated and one element of such simulations were virtual user models. In the further course - mainly in the 1980s - the features of today's Human models became more mature.

Some special solutions were used and improved others were just redesigned, but the actual human models have been more versatile and comprehensive in their functions. This led to the fact that the number of models has decreased, because the effort to create new models has become much more complicated [6].

User modeling on the other hand is an established area of HCI (Human-Computer Interaction). However, most of the conventional user models do not consider possibilities of unexpected error modes or influences of body shapes and movements of users. The scope of usability assessments also tends to ignore spatial relationships between users and objects of their environment. Furthermore, user models have been implemented by proprietary infrastructures to manage and query their respective models. These models are in the first place complex data structures revealing many similarities to VUMs in the way they are structured, managed and how they are consumed by services.

Virtual users have also been suggested for testing, such as trying the capacity of search engines or other interactive web applications in handling different cases, but also mass usage and scalability. This approach was practiced already over 20 years ago [7], and still is being used [8]. Yet these approaches do not require individual virtual entities, but can work on statistical models. Toru Nakata, et al reported of a virtual user prototype that simulates human machine interaction including errors in body actions and mistakes in cognitive decision, they used it for simulation of a car driver, the virtual user model generates human-like body movements and error escalations in cognitive process [5]. In this respect, many important software models were created such as *Anthropos BoeMan* (1969), *CyberMan* (1988), *Franky* (1988), *CombiMan* (1988), *ERGOMan* (1988), *TEMPUS* (1988), *CrewChief* (1990), *ErgoMAX* (1998), *Ergo* (1998) *or Safework* (Safework 2000). Many of these models were developed as standalone models or were partially merged or integrated into other models.

In the following section an overview of methods and tools based is provided, which are from the view of the authors suitable for inclusive product development and especially applied in the early phases of product development: sketch, design, and testing/evaluation. Special focus is upon the review of methods and tools which are based upon the utilization of virtual user models.

2.1 Methods and Tools for Supporting the Sketch Phase

For the sketch phase a mixture of qualitative and quantitative methods are common such as user studies, field trials, market studies or interviews. Since the initial product development steps are characterized by creativity, innovation and a need to react flexible on changing requirements, software tools supporting directly such product finding tasks are rarely in use. On the one hand especially for idea generation creative techniques like brainstorming or 635 methods are well known and used in product development. Ideas are not only based on the tacit knowledge of developers. The input to these phases comes from several internal and external sources like customers (lead users), competitors, marketing (market pull) and research and production (technology push) [9], [10]. On the other hand Information Technology is limited to an indirect role, such as providing structures for a quick idea exchange as in Mind-Maps or the preparation of sketches and initial drawings like in graphic design software such as ADOBE Illustrator.

From the academic domain, especially in HCI-Human Computer Interaction, a variety of methods and tools exist for designing software user interfaces, under the consideration of specific end user needs. However, only limited efforts have been spent so far in advancing methods and tools for designing physical or mechanical interaction components of consumer products in an inclusive manner [11].

One method with special focus on inclusive design is the “Inclusive Design Toolkit”, which was developed by the Engineering Design Centre of the University of Cambridge [12]. The toolkit can be considered as an online knowledge repository of inclusive design knowledge and interactive resources, proposing inclusive design procedures and inclusive design tools which designers may consult to accompany them through their product development process. For supporting the sketch phase the tool provides general design guidance recommendations. Although the Inclusive Design Toolkit provides a limited set of personas, the methodology is strongly dependent upon a comprehensive knowledge of the product developer in order to transfer evaluation results into design improvements.

When focusing strictly upon the design of specific physical components of products, only two model-based design methods could be identified by the authors, which are capable of supporting the sketch phase of a product, under consideration of the needs of users regarding accessibility to the envisaged product. These two methods are based upon the configuration of pre-defined user models which have synergies with the context used for existing virtual user models. Although the methods are applied for the conceptualization of wearable computing systems, considered mechanical components can also be applied for technically advanced consumer products up to a certain extent (e.g. mobile phones, etc.).
In the first approach, a "mobile and wearable computer aided engineering system" (m/w CAE System) was proposed by Bürgy [13]. By defining a constraint model, scenarios are described where support for a primary task is needed. Based on this model, existing comparable solutions are identified or new adapted systems are drafted. The description of an exemplary scenario is realized by using elements of four sub models: (a) the user model, (b) device model, (c) environment model, and (d) application model.

The constraint model is made applicable by a software tool called *ICE-Tool* (Interaction Constraints Evaluation Tool), which allows to set up the constraint models, and to look up implementations for similar scenarios in a database. The intention was to make design knowledge from past applications available even to domain experts who are not systems developers. Because of a strong abstraction, a simple communication of scenario elements is very limited. The sub models are intentionally kept very simple, since the main focus of this approach is the identification of similar work situations. Also, most of the attributes of the sub models are defined by binary decisions, making detailed design decisions in combination with the simple sub models. A shortcoming is the small number of different interaction devices to choose from. For instance, the device model cannot distinguish a device needing tactile interaction from one which does not.

The other approach for a design support regarding mobile hardware components was published by Klug in 2007 [14]. The proposed solution consists of three parts. The first part is focused on the documentation and communication of specific use cases. Shortcomings in these fields lead to misunderstandings and false assumptions which will produce many subsequent errors during the design process. This challenge is met by the definition of models allowing a correct representation of wearable computing scenarios to enable a systematic documentation of use cases. The goal is to make the representation comprehensible for the whole design team and thus enabling the interdisciplinary communication between the members from different backgrounds. The author points this characteristic out to be of outstanding importance on the way to the design of an optimal wearable device for a given scenario. Another part of solution deals with the provision of models and tools supporting the selection and configuration of suitable devices. The last part finally, considers the mutual influence of different interaction devices on each other and the work wear of the user, thus taking the aspect of multitasking into consideration. An integrated user-centered design process is presented, supported by three models: a work situation model, a user model, and a computer system model. Based on these, a scenario can be simulated, identifying the compatibility of an interaction device with it. In Fig. 2 the components of the model are illustrated, which represents the basis for the design method.

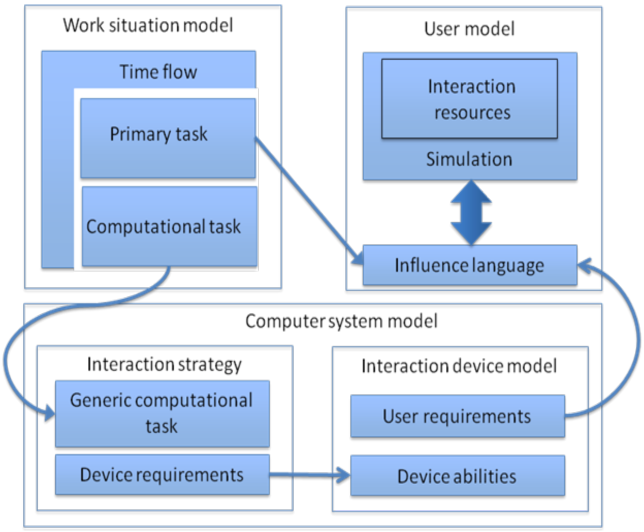

Fig. 2 Components of the model [14]

Due to the intense and specific design to a certain type of use case, the approach lacks of easy adaption to scenarios. The work aims to describe use cases in a very fine granularity which makes it suitable for well-defined, recurring tasks in a fixed, well-known environment. Use cases with changing environments and slightly unpredictable tasks cannot be described on such a high level of detail without limiting the flexibility, necessary to cope with dynamic change.

2.2 Methods and Tools for Supporting the Design Phase

In the design phase most of the development tasks and sub-tasks are typically supported by so called Computer Aided Technologies (CAx), while "x" stands for a bunch of applications [6]. The most common application of these is Computer Aided Design (CAD). Originally focused on the preparation of technical drawings, nowadays nearly all systems provide 3D models of parts and assembled products based on true to life parameters. In order to cope with the needs in order to achieve inclusive design of a product, several CAx applications provide virtual user models as extensions. The most widely used applications in companies include Pro/Engineer, CATIA, and Solidworks [5]. High-End CAD systems as the mentioned ones are extensible through digital human model plugins, such as *Manekin, Ramsis*, *Jack*, or *Human Builder*, to name just a few. CAD tools are further based on a so-called parametric design. "Parametric" means in this context, that all parameters are accessible as variables (incl. their values). This way the user is able to define formulas, rules, and similar relationships between parameters. A given design of a product (e.g. a model of a coffee-pot) can be linked to only a few explicit parameters (e.g. chamber-volume, pot-handle diameter), by setting all other parameters in a direct mathematic correlation. Hence if one of those explicit parameters is adapted the 3D model is morphing according to the predefined formulas. Those formulas and rules can not only be used for such a "design automation", but also for checking a concrete design against given constraints (e.g. to check the pot-handle diameter against to-be values). In the scope of providing a design support for the inclusive product design, it should be noted that contemporary virtual user models are often limited regarding the possibility of representing specific user groups such as users with certain physical impairments [6]. In this respect the simulation of human fine motor skills such as movement of single fingers and joints exceeds the capabilities of most virtual user models available today.

2.3 Methods and Tools for Supporting Testing and Evaluation

A way of testing via simulation is by building Virtual Reality (VR) environments to illustrate novel technology, and let user representatives evaluate the concepts by watching the VR simulation and interacting with it. Up to a certain degree this allows to receive early user feedback to system concepts, long before real prototypes are available. This approach is used to let user representatives have an immersive VR-based 3D experience of a future system [15]. The Immersive Simulation Platform presented in this research called VAALID, immerses the user in a virtual environment, allowing the user to experience some situational aspects of the virtual environment [16].

A shortcoming of this approach from the point of view of the authors of this paper is that the evaluation of a product is dependent upon the participation of real users. From a technical point of view the system cannot be integrated with e.g. existing CAx applications, and needs a very powerful computing environment in order to take advantage of the full simulation capabilities of the system. A similar VR approach was used as a way to collect user feedback throughout the design of wearable computing IT to support firefighters [17], [18]. Here virtual and pervasive prototyping was used to test and design supportive technologies (ubiquitous and wearable technology) for the very specific domain and user group of firefighting. Instead of elaborate user models, simple ones were used in conjunction with strong user participation in simulation sessions.
Beside simulation, VUMs can be used to detect accessibility and usability problems of human interface designs. In the area of accessibility only one case study was identified, which is the *HADERIAN* system, which is an extension of the CAD Software *SAMMIE CAD.* HADERIAN was especially developed to study tasks for elderly and disabled persons. The aim pursued in this approach is to detect accessibility issues during the interaction between users and ATM machines [19]. One of the disadvantages of this system is that the "hand model" of the VUM is not sophisticated enough to grasp and manipulate objects like mobile phones [5].
For ergonomic analysis of product designs, tools incorporating virtual user models are available mainly in the area of product lifecycle management e.g. Tecnomatix (Siemens/ UGS) [20].

This system is using a model called *eM-Human*. In the military domain, there is a VUM called *Santos*, which was developed in the frame of the Virtual Soldier Research Program of the University of Iowa [21]. It uses accurate biomechanics with models of muscles, deformable skin and the simulation of vital signs. With this system analyses of fatigue, discomfort, force or strength can be done. Furthermore modules for clothing simulation, artificial intelligence and virtual reality integration are available for real-time systems. Some other models like the Boeing Human Modeling System (BHMS) or the System for Aiding Man-Machine Interaction Evaluation (SAMMIE) complete this listing [22].

2.4 Shortcomings of Analyzed Design Methods and Tools

Corresponding to the analysis in the last section, the shortcomings of the considered methods and tools for inclusive product design are highlighted in the table below.

Table 1. Methods and Tools for Inclusive Product Design

Design Method/Tool	Shortcoming
Methods and Tools for supporting the sketch phase	The model-based tools are either very use case specific (scenarios with high granularity), or they are defined on a very abstract level. The user models are based upon the "personas" approach, where standardized person profiles (e.g. European, male, 36 years, etc.) are provided to the designer. They do not consider possibilities of unexpected error modes or influences of body shapes and movements of users. An easy adaptation, such as the modification of rules, the extension on components and scenarios is not possible. The tools also fail to integrate with the design and evaluation phase. There is also the danger of inducing false assumptions which may lead to sub-sequent errors within the design process. Only component recommendations are provided, but not design recommendations (e.g. the keys of a keyboard should have a certain size and shape), which is definitely a shortcoming from the point of view of inclusive design. Knowledge repositories as it is the case with the Inclusive Design Toolkit only provide very rudimentary recommendations regarding design guidance.
Methods and Tools for supporting the design phase	Available digital human models are not sufficiently defined regarding typical physical impairments of users. Up to date there are no CAD systems available that provide the designer with specific recommendations about the appropriate design of an envisaged product or about the type of mechanical components which could be used in order to maximize accessibility of the product.
Methods and Tools for supporting Testing/ Evaluation	Contemporary tools are usually specific to a certain branch (automotive, aero-space, military). A configuration of the virtual user model is restricted to the modification of motor movements. It was identified that the hand models of some tools such as HADERIAN are not sophisticated enough in order to grasp and manipulate objects like mobile phones. Virtual user models fully representing users with impairments are rarely available, especially in relation to mild and moderate impairments.

Based upon these shortcomings, it was possible to identify the constraints for defining a virtual user model. These were consulted for the conceptualization of an inclusive design method based upon a virtual user model in chapter 3. In order to offer qualitative and quantitative design recommendations to the product developer, the virtual user model is viewed as a context model which sufficiently represents users with impairments, and relates them with technical properties of potential user interfaces of consumer products.

3 TOWARDS A MODEL-BASED APPROACH FOR INCLUSIVE DESIGN OF CONSUMER PRODUCTS

3.1 Conceptualization of the VUM

Since a virtual user model as an abstract representation of an envisaged user group which includes a description of the underlying context, it is legitimate to consider the VUM as a context model. Context represents on a universal scale, the relevant aspects of the situations of the user groups [23]. Hence, a context model describes the characteristics, features, and behaviour of a specific user group. Complementarily it also includes the aspects related to the tasks, interactions, user interface, and the environment, where she or he interacts with consumer products.

Accordingly, the VUM as proposed in this paper possesses different facets for supporting the development process. We suggest calling the approach "virtual user concept" because it is a design concept based upon the development and implementation of a virtual user model. Fig. 3 provides an overview of the underlying concept emphasizing the interplay between the virtual and real world. The virtual user model is based upon real-time accessibility needs of the envisaged end user groups. In the virtual world the VUM interacts with the sketch, design and evaluation phase of a product. It is foreseen that the support by the VUM works in the following way: In the initial sketch phase, a support appears in form of text-based recommendations with respect to potential user interface elements. Up to this point, the recommending character of the Virtual User Model can be compared to an expert system as defined in [24]. However, expert systems are usually highly domain specific, thus are not easily adaptable to other domains. Next to the feature that the VUM should be easily adaptable to other contexts by the designer, the Virtual User Concept goes beyond the provision of recommendations. In the design phase the VUM will guide the designer with templates and design patterns for interaction components of consumer products. For the evaluation phase, a 3D virtual character in a virtual environment will be established in order to evaluate a conducted product design against predefined usage scenarios. After several iterative development cycles, the results are then used for realization of a physical prototype and final product in the real world.

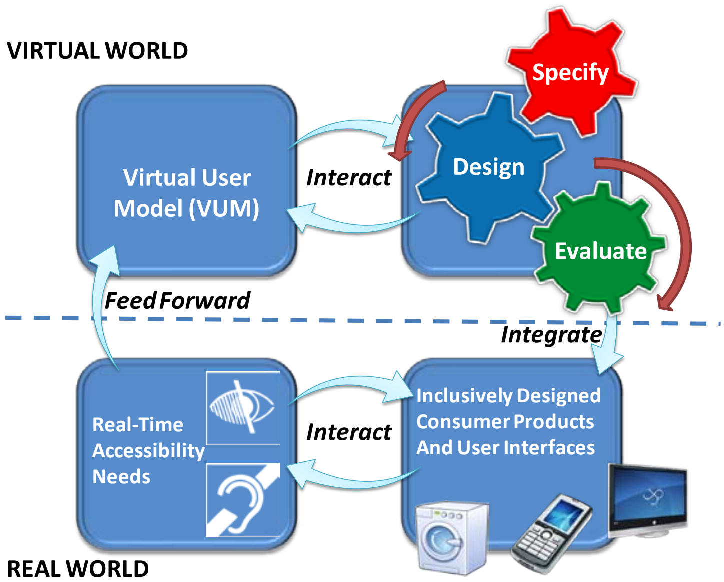

Fig. 3 Overview of the Virtual User Concept

In summary, the Virtual User Concept should go beyond existing approaches by:

- Accompanying the design process from the scratch until the final CAD design cycle, by providing different standalone recommendation systems for the idea finding stage, the sketch phase and components for integration with CAD systems,
- Incorporating different accessibility features in the user profiles,
- Adding new reporting mechanisms e.g. web based reports and visual responses in the virtual user itself.

To make this approach more comprehensive, an example is presented focussing upon the sketch and design phase: A designer is planning to design a new product such as a mobile phone and would like to incorporate accessibility features into the new product. The designer invokes the recommendation system, selects from the device list “mobile phone” and configures from the “target user group” the required target user group or groups. Based on the entered information, the system presents the designer with a list of existing use cases and additionally links to existing guidelines. The designer then creates the preliminary layout of the new mobile phone, saves it, and imports it to the recommendation system. The system then displays more accurate recommendations relevant to the layout and the selected target user group. For instance, a recommendation could state that in order to better meet the needs of users with manual dexterity impairments, the distance between the keys of a mobile phone should have at least a distance of n millimetres. Based upon these kinds of recommendation, the design of the user interface component can be completed. In the final phase the designer’s objective would be to assign a scenario to the virtual user – this means the specified task and environment of the first phase would now be manifested in a virtual environment. For example, this could be ‘making a phone call in a noisy outdoor environment”. For this reason the designer runs a 3D virtual user system, which could be a part of the CAD application, or a separate application which allows the import of CAD designs while providing appropriate analysis tools. After the required environment has been created and the tasks have been assigned to the virtual user, an execution procedure reports the results visually to the designer. Based upon the results, the designer can return to a preceding phase and make adaptations to the design, until the final user interface design is accomplished.

3.2 Implementation of the VUM

The VUM should possess the capability to determine recommendations for appropriate interaction components for a consumer product. Therefore, it should incorporate well-defined partial models which are assigned by the context to determine proper recommendations. A suitable taxonomy for the VUM may include at least the following sub-models:

- **User Model**, where all information about a Virtual User such as physical impairments or diseases are stored. User Models could be divided into several subgroups (Profiles), where for every criterion the profiles are divided into different levels of impairments. Additionally there are mixed profiles describing the group of elderly people suffering upon a mixture of hearing, sight and dexterity impairments.
- **Component Model** describes specific components and adds functionality to specific instances. E.g. a button can be pressed, so the button consists of the functional attribute of a 2 state switch. This model is used to connect recommendations with components especially in the second phase, where the user input is component related.
- **Model for Recommendations**, where guidelines and experience information are stored. These consist of the predicates “Name”, “Text”, “Summary”, Rules, Phases and an Attachment, where e.g. Sketch Phase Template Layers can be stored. A component attribute defines rule sets for the design phase, if a recommendation is related to a specific component or component functionality like “Audio Output”.
- **Environment Model,** where all data of the environment is stored. That includes the physical conditions of the environment of the real world, objects and characteristics of the environment etc.
- **Task Model,** describes how to perform activities to reach a pre-defined goal. This model may be based e.g. on Hierarchical Task Analysis (HTA) providing an interface, where the designer can define actions of the user for the evaluation in the virtual environment.

In relation to functional requirements, such as gaining component recommendations as an output, the virtual user model needs to be able to parse the sub-models using logical constraints. This is necessary in order to build an inference model with all relevant data. For the implementation, an architecture is proposed, which includes the VUM as a knowledge base. Fig. 4 shows the system architecture of the overall system for implementing the VUM. It is divided into the parts: the backend, where all data of the VUM is stored, the frontend, where company-specific design and testing applications, as well as all client-specific features to obtain recommendations (recommendation module) are integrated. The middleware layer provides a seamlessly accessible connection between the front end applications and the reasoning engine with a socket connection handler and socket server.

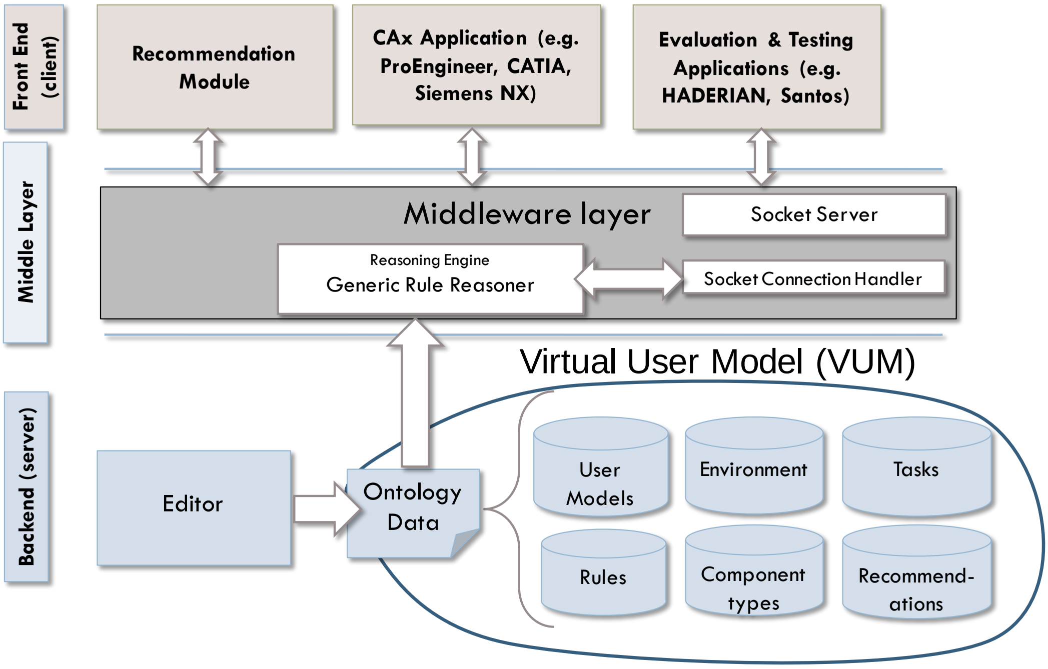

Fig. 4. Architecture for implementation of the VUM

3.3 Inference of the VUM in the Sketch Phase

The sequential creation of inference models of the Virtual User Model is divided into 4 steps, which apply specified rule sets by every one step as illustrated in Fig. 5:

1. **Applying of user model Rules**
   The General Rule Reasoner uses the user model rules to define all instances of the user model class as members of specified WHO ICF profiles (e.g. a specific profile for moderate hearing impaired people).
2. **Generation of initial Recommendations**
   This step is the same as the second step, with the difference to use the recommendation rules and instances based upon user model profiles.
3. **Creation of environment recommendations**
   This step creates classes based on the id names of every environment, and adds all textual and component recommendations, which were reasoned by the environment rules, as members of these new recommendation classes (e.g. a recommendation class for an instance of the environment). These rules can also use the previous defined recommendation classes.
4. **Creation of task recommendations**
   The last step creates all task related recommendations based on task rules and all previously defined recommendations. This procedure is the same as the creation of environment recommendations, all tasks id names define dynamically created classes, which contain recommendations for specific tasks.

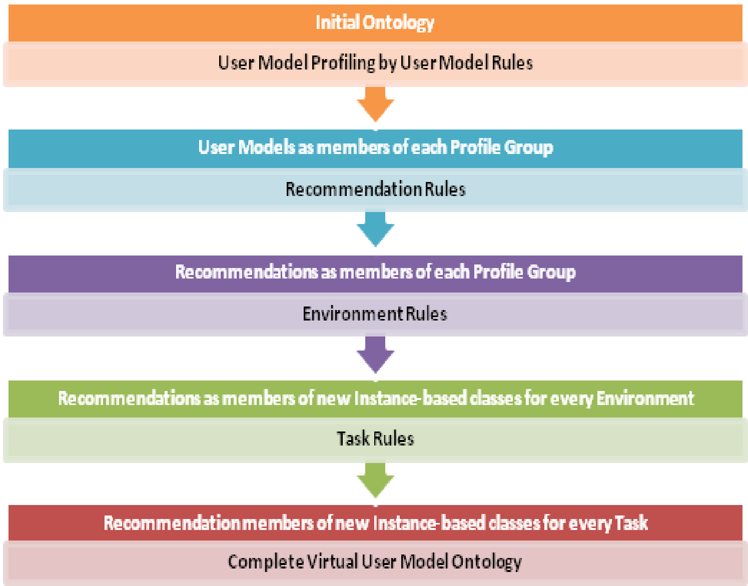

Fig. 5 Iterative Creation of Recommendations during the Sketch Phase

4 CONCLUDING REMARKS

The presented design approach based on the described virtual user concept is capable of supporting the product development process in the early stage before realizing of prototypes. It should however, not be understood as a substitution of real users per se, but moreover as complementing the involvement of real users - an opportunity to minimize the effort of applying quantitative and qualitative studies in the early design phase. The benefit for mainstream manufacturers of consumer products is obvious as they would be able to develop their products in an inclusive manner, making them accessible for users with mild to moderate impairments, thus at the same time remaining attractive for non-impaired users as well. Although the proposed virtual user model has already been technically implemented, the focus of this paper was mainly to discuss the model-based design approach from a conceptual perspective. The data basis of the VUM and the technical implementation of the recommendation system are described comprehensively in the project reports of the VICON project (www.vicon-project.eu). In this respect it was already possible to demonstrate the feasibility of the approach. In the next stage it is foreseen to investigate how the virtual user model can be effectively used by individual product designers throughout the sketch and design phase of a selected consumer product. A main challenge will be to seamlessly integrate the VUM into the existing product development processes of manufacturing companies, e.g. integrated into mainstream CAD applications such as ProEngineer and Siemens NX. In this respect, design support through the VUM should involve presenting qualitative and quantitative recommendations based on the specified values in the CAD software. These recommendations may consist of a unified set of guidelines, interaction components and additional information regarding the specific design of a component. In order to obtain the practical value of the approach, we shall therefore test and validate the VUM based upon two real design cases; a mobile phone and a washing machine, in close cooperation with two well-known consumer goods manufacturers. The aim shall be to confirm the benefits of the proposed design approach, but also to identify the limits of a virtual user model-based design support to the research community and design industry.

ACKNOWLEDGEMENTS

This work has been done under the research project VICON (project No. 248294) funded by the European Commission under the ICT Framework (ICT-2009-7.2). We wish to acknowledge our gratitude and appreciation to all the project partners for their contribution during the development of various ideas and concepts presented in this paper.

REFERENCES

[1] Silva, F. and Almendra, R., Inclusive Design: A New Approach to Design Project. *A Portrait of State-of-the-Art Research at the Technical University of Lisbon*, 2007, pp605-621.

[2] Chimbuya, A., Barriers to adopting inclusive design. 2008.

[3] VICON-Consortium. D1.2 Survey of Design Frameworks and Tools. 2010.

[4] Naumann, A. and Rötting, M., Digital Human Modeling for Design and Evaluation of Human-Machine Systems. *MMI-Interaktiv Nr. 12, April 2007*, pp27.

[5] VICON-Consortium. D1.3 Virtual Users in a Human-Centred Design Process. 2010.

[6] Mühlstedt, J., Kaußler, H., Spanner-Ulmer, B., Produktgestaltung, P., Programme in Menschengestalt: digitale Menschmodelle für CAx-und PLM-Systeme. 2008.

[7] Olsson, K.A. and Bergmann, M., A Virtual User Simulation Utility. *HP Journal*, 1988.

[8] Thurmann, E., Virtual User Simulation. 2005.

[9] Pahl, G., Beitz, W., Feldhusen, J. and Grote, K., Pahl/Beitz Konstruktionslehre: Grundlagen erfolgreicher Produktentwicklung. Methoden und Anwendung. (Springer 2006)

[10] Westkämper, E., *Einführung in die Organisation der Produktion*. (Springer, 2005).

[11] Kirisci, P. and Thoben, K.-D., Vergleich von Methoden für die Gestaltung Mobiler Endgeräte. *icom - Zeitschrift für interaktive und kooperative Medien*, 2009, 8(1), pp52-59.

[12] Clarkson, J., Coleman, R., Hosking, I., Waller, S., *Inclusive Design Toolkit*. Cambridge Engineering Design Centre, 2007.

[13] Bürgy, C. and Garett, J., Situation Aware Interface Design: An Interaction Constraints Model for Finding the Right Interaction for Mobile and Wearable Computer Systems. *19th International Symposium on Automation and Robotics in Construction* ppS.563-568 Gaithersburg, Maryland, 2002.

[14] Klug, T. and Mühlhäuser, M., Modeling human interaction resources to support the design of wearable multimodal systems. In. pp299-306. (ACM 2007)

[15] Nature, D., Accessibility and Usability Validation Framework for AAL Interaction Design Process. 2008.

[16] Schäfer, J., Machate, J., Maly, J. and Röder, P., VAALID: Eine Entwicklungs-und Simulationsumgebung für AAL-Projekte. *Ambient Assisted Living-AAL*, 2010.

[17] Klann, M., Ramirez, L., Lehnhoff, A. and Dyrks, T., Playing with Fire: towards virtual prototyping of wearable computing for highly situated contexts of use. *IFAWC 2006*, 2006.

[18] Klann, M., Playing with fire: user-centered design of wearable computing for emergency response. In. pp116-125. (Springer 2007)

[19] Summerskill, S., Marshall, R., Case, K., Gyi, D., Sims, R. and Davis, P., Validation of the HADRIAN System Using an ATM Evaluation Case Study. *Digital Human Modeling*, pp727-736. 2009.

[20] Demirel, H. and Duffy, V., Applications of digital human modeling in industry. *Digital Human Modeling*, 2007, pp824-832. (Springer 2007).

[21] Zheng, C., Xue, Q., Ren, X. and Yu, P., Research of virtual dismounted mechanized infantry squad combat modeling and simulation based on DI-Guy. In, *1*. ppV1 (IEEE)

[22] Sundin, A. and Örtengren, R., Digital human modeling for CAE applications. *Handbook of human factors and ergonomics*, 2006.

[23] Hull, R., Neaves, P., Bedford-Roberts, J., Towards Situated Computing. In *International Symposium on Wearable Computers*. pp146-153

[24] Castillo, E., Gutiérrez, J.M. and Hadi, A.S., *Expert systems and probabilistic network models*. (Springer Verlag, 1997).