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CONSIDERATION AND MODELING OF USE PROCESSES IN COMPUTER-AIDED CONCEPTUAL DESIGN: A STATE OF THE ART REVIEW

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If conceptual modeling and simulation of consumer durables could include consideration of use processes, designers could more successfully anticipate the interaction of products with users in a use environment. This is the basic idea behind our research into computer-aided modeling and forecasting product-use processes. This survey investigates the current state of the art, that forms the basis for companies or researchers developing systems in this area. It includes overviews of (a) definitions (b) relevant achievements in this field, and (c) research in related areas, such as ergonomics, human-computer interaction and machine design. In recent years, there has been no significant development of novel, dedicated use-process models. Current models represent discrete actions, observed from use of existing products or prescribed by the designer. Simulation techniques are applied to deal with continuous changes, predicting the behavior of the product and its environment, but typically not the user. Yet, promising techniques for simulating humans are emerging, for instance in computer-graphics animation. New integrated techniques for simulation open the way to quantitative and more accurate predictions of the use process, but they cannot handle the multiplicity of possible use processes resulting from different users in different environments. In this respect, the development of use-process models with increased knowledge content and facilities for integration with simulations can give a solution.

1. Introduction

Design of durable consumer products is supported by various software packages. An area not yet covered by these tools is modeling and forecasting of product use. Such additional support would enable designers to anticipate various use circumstances and develop products that are more successful on the intended market. Current CAD systems typically offer the designer means that support building *artifactual models*. Various books, papers and articles have reviewed common models of artifacts to compare representations and to explore integration possibilities. However, none of the advanced artifact models can offer a complete view of real-life products. One of the reasons is that artifact models focus on the spatial and physical manifestation of the product. Hence time-related or process aspects are not directly addressed. These are covered separately, by means of process-modeling techniques.

A representative set of product-related process modeling techniques was reviewed in (Van der Vegte, 2000). The goal was to investigate opportunities of integrated artifact-process modeling. It was concluded that existing approaches do not support direct two-way transitions from the artifact view to the process view, and vice versa. Some modeling techniques, notably finite-element-based dynamic simulations, provide support to transit from an artifact model to a behavioral artifact model. Behavioral simulations are generally implemented as stand-alone processes (for instance, modeling how deformations develop in a falling product hitting a floor). There is no way to tell how preceding processes initiated the simulated process. The designer has to make out whether the result of simulation calls for modifications in the artifact design. Thus, behavioral models can only implicitly influence the evolution of the artifact model. We cannot couple independent simulations to each other and evaluate simulation results in the context of more substantial or higher-level processes that a product goes through over a longer period of time. Usually, a higher-level process contains countless low-level processes of the extent that is covered by individual simulations. One of these higher-level processes is the use process of a product.

1.1. Research Context of This Survey

1.1.1. Focus

In the use process, a product interacts with its user(s) to fulfill its purpose. Our research project focuses on the inclusion of use-process modeling and forecasting in computer-aided design. Together with the use process, other higher-level processes like manufacturing and dismantling make up the so-called life cycle of a product (see subsection 1.5). The use process has already been identified as a typical area where design models fail to capture the dynamic aspects of processes (Buur & Nielsen, 1995). It presents specific challenges to designers, especially when so-called consumer durables are concerned. Consumer durables are products that yield services or utility over at least one year, rather than being completely used up at the moment of consumption (Bannock, G. et al, 1998; United Nations, 1988). After Dirken (1997), Li, (1999) and Murdoch (1983), typical use-related characteristics of consumer durables are:

1. The products are intensively and/or frequently used by human users
2. They are mostly in direct contact with skin and sense organs
3. They are usually wearable or movable
4. They can often be seen as specialized extensions of natural human functions
5. Users are often inexperienced or untrained.

Especially the last-mentioned characteristic, i.e. the limited experience of users, poses problems to designers. It implies that the use process might not take place as expected – for instance, not according to the user manual (Margolin, 1997). Therefore, designers need to predict or anticipate alternative forms of use (Rooden, 2001).

Focusing strictly on consumer durables would severely reduce the value of this review. Therefore, we consider use aspects for a much wider range of products here.

1.1.2. Primary Goal

The primary goal of the research project into use-process modeling is to develop a computer-supported method that enables designers to:

- model use processes of existing products;
- forecast use processes of redesigned or new products;
- incorporate use aspects in product development through use-process simulation;
- improve products by considering effects of regular, irregular and incidental use.

Therefore, our review extends to

- analysis of relevant definitions from literature
- review of the research already done in the field of modeling and forecasting use processes in computer-aided product design
- investigation of what has been done in the related areas such as machine design, ergonomics, man-machine interface, human-computer interaction, biomechanics and cognitive science.

1.1.3. Forecasting, Prediction and Models

Beside the specific focus on the use process, this paper covers the principal issues of *forecasting, prediction* and *models*. Forecasting and prediction are usually treated as synonyms. According to Honderich (1995), prediction is ‘specifying occurrences in advance of the fact’. In general, only rational predictions are considered valuable. Rational predictions are always based on induction - a projection from past experience. Prediction is always related to *processes*, which represent the changes in time. The definition of a *model* given by Rodenacker (1991), is: ‘an object M is a model of object O, if analogies exist between O and M that allow us to draw conclusions about O’. Apparently, these conclusions can be derived from M. In predictive modeling, they will have to contain statements about the future states of O based on previous known states of O. Typically, knowledge from both experience and projections is laid down in a model.

1.2. Scheme of the Survey

In section 1.2.1, we will identify global appearances and characteristics of use processes and introduce various definitions. In section 2, we investigate how the use process is currently taken into account during product design. In section 4, we discuss the process models that are currently applied in the description of use processes. In section 4, models of the so-called actors in the use process are reviewed, as they appear cover aspects not covered by process models. In section 5, we discuss how combining process models and actor models can lead to improved support of use-process forecasting in computer-aided conceptual design, and what is still missing in the combination. In section 6 we conclude the review and present a possible solution for the open issues.

1.2.1. Appearances and Characteristics of Use Processes

‘Use’ is the pivotal expression to describe a specific part of the life cycle of a consumer durable. It is a recurring topic since the end of the 1960s. The number of papers on use-process research has especially increased due to the increasing need for establishing interaction between humans and computer systems, or daily-life products such as cars, audio-visual equipment and domestic appliances. This lead to the emergence of attention fields like Man-Machine Interface (MMI) and Human-Computer Interaction (HCI) research, which stand close to use and usage. For clarification, we begin with discussing some general definitions, and then we elaborate on the process aspect of use.

1.3. General Definitions of Use

According to a general definition, use is ‘employment or application to a purpose’ (Fowler & Fowler, 1961). The words ‘employment or application’ do not exclusively apply to use of products – they may also refer to ‘use of land’, ‘use of space’, ‘use of time’ etc. In this survey, we will concentrate on use of products. In the context of industrial design, Dirken (1997) defines use as ‘direct handling of technical aids to reach a particular goal’. He argues that for a product ‘to use’ always implies working in service of, and having contact with, the human body and brain. Terms derived from the word ‘use’ are ‘usability’ and ‘user’. From the perspective of product functions and operations, *usability* is the term relating to qualities of use. This aspect will be specifically addressed in subsection 2.1. The word *user* grammatically means 'the person who uses' the product. It is one of the three basic actors, or participants, that are typically identified in product use: (1) the user, (2) the product and (3) the environment (e.g., Li, 1999; Roozenburg & Eekels, 1995; Chandrasekaran & Kaindl, 1996). This triplet represents entities in space rather than capturing the time aspects that make use a process. The next subsection further clarifies the process aspect of use.

1.4. Use as a Process

A process is (a) a course of action, (b) a natural or involuntary operation or (c) a series of changes (Fowler & Fowler, 1961). In the design and engineering literature, the process aspect of use is often addressed by referring to the time-related constituents as 'actions' (e.g. Chandrasekaran & Kaindl, 1996, Kanis, 1998). It does not need further explanation that actions are closely related to behavior. A clearly marked-out distinction was not found, but the investigated literature refers to action both in singular and plural, whereas behavior is always referred to in singular (i.e. 'actions' is commonly used, but 'behaviors' is not). From this observation, we conclude that actions represent the discretized form of behavior. Actions considered at a general level, or the level of system specification, can have multiple distinct occurrences when observed in real life. Both the generic actions and their occurrences can be counted or numbered, whereas 'behavior' refers to some observable continuous change which cannot be counted. Another point of distinction is that actions are 'active' by nature. Cain (1969) states that use is 'the fundamental purpose of every product'. He considers 'user' a synonym of 'operator'. In his opinion, use is built up from so-called details of operation. The details are (1) control – 'actions by the operator, bringing to effect function' of the product, (2) display of information by the product to the operator, and (3) end results (of what Cain calls the 'the function' of the product).

Function is a central theme of the traditional 'European School' of design engineering. According to Hubka & Eder (1988), who strictly associate all product-related processes with functions of the product, function is the purposeful part of product behavior. Use is referred to as 'usage'. It corresponds to external properties that can be regarded as the goals of the technical system/product, and it is not addressed as a process. Horváth (1998) elaborates on the distinction between function and behavior. He claims that function is intended operation that is a reply to the requirements for some operation. Behavior is the observed or observable operation of a technical system or product. Thus, a function is realized by operations and the behavior expresses how the technical system or product performs the operation.

Chandrasekaran & Kaindl (1996) explore the relationship between use and function in a process context. They state that a product[1] has a function defined in terms of effects on the environment wanted by the user. The use process is made up of product functions and user functions, that can be expressed as transitions between states of the user-product-environment (U-P-E) system. Unlike Cain, who sees the use as 'the user operating on the product', they suggest that 'use' corresponds to 'user behavior' in the same way as 'operation' corresponds to 'device behavior'. Chandrasekaran & Kaindl also distinguish user *actions* from product actions. They do not clearly set apart 'function' and 'action'. According to Kanis (1998), actions by the user can have effect on the product and on the environment. Manifestation of the functioning of the product can have effect on the environment as well as on the user, and environmental 'factors' can have effect on the user and the product (notice the suggestion that an environment does not act).

If the product is strictly software, behavior-effect relationships are more restricted, since software and the world around the system containing the software cannot influence each other in a direct physical way. In software engineering – a domain outside the primary scope of this article – a

[1] In the original article, Chandrasekaran & Kaindl consequently call products 'devices'.

distinction is made between the system (product) and the environment (including the user). Gunter et al. (2000) distinguish environment phenomena and system phenomena. Environment phenomena can be visible to the system but they cannot be controlled by it and vice versa.

According to Roozenburg & Eekels (1995) the behavior of the U-P-E system as a whole can cause changes in the environment and the product. In the context of industrial design, Li (1999) defines human action as users' goal-directed behavior with artifacts or toward artifacts. Use is often referred to as *inter*action between user and product, or between user, product and environment (Chandrasekaran & Kaindl, 1996; Warrell, 1999; Li, 1999, Janhager, 2001). Interaction is 'a situation in which the behavior of one system (in our case the user, the product or the environment) affects or is affected by another system' (Clugston, 1998). 'To affect' means 'to have an effect on' (Manser, 1997). Applying these definitions, the interaction aspect of use can be considered to link *behavior* and *effect*. In the case of interaction, the behavior of one actor of the use process has effect on another actor, or on the behavior of another actor (user, product or environment).

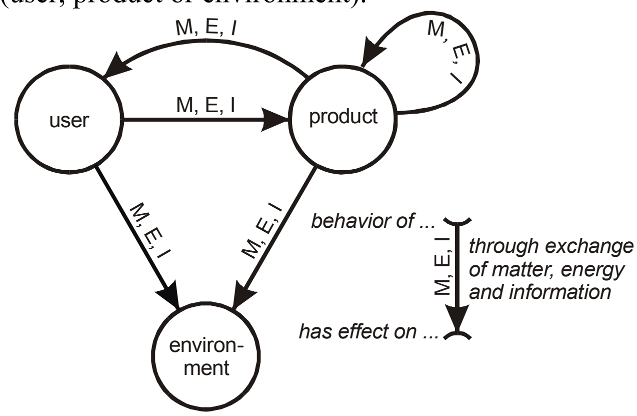


Fig. 1 Interactions between the three actors in the use process as discussed in literature.

How does this interaction take place? In his description of relationships between humans and machines (or devices, products), Roth (1982) characterizes both humans and machines as capable of storing, transferring, changing and merging matter, energy and information (M, E, I). The crucial role of this triplet is widely acknowledged, not only in German literature on design methodology (e.g. Pahl & Beitz, 1988) but, for humans, also in the 'theory of living systems' (Miller, 1978). Fig. 1 shows the behavior-effect relationships between user, product and environment found in literature.

Returning to product use, we can recapitulate the following statements about the use process that is generally agreed upon in literature:

- The use process is an interaction between user(s) and product(s) based on initiation by user(s)[2] in the environment of the product.
- Interaction is based on the exchange of matter, energy or information.
- Use is a particular form of existence of the product. It is also a phase of its life cycle, where it is supposed to fulfil its function, and where its observable operation (behavior) takes place
- Use can be derived from, and depends on, behavior of user(s), which leads to behavior of the product.
- Behavior of the product on its turn leads to effects on the environment and/or on the user, which may influence the further course of the use process.

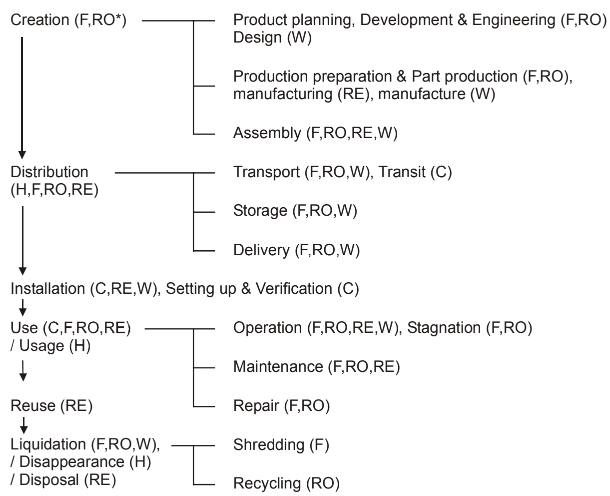
[2] Note that the initiation, or 'bringing to effect the function of the product' does not have to be direct. An alarm clock may show initiative by warning its user, but the prerequisite is that the user has taken the initiative to switch on the alarm function.

- The use process consists of actions – performed both by the user and by the product. About the distinction between action, behavior and function, literature seems to agree that (a) user actions are a subset of user behavior, (b) product actions are a subset of product behavior, and (c) the functions of a product are a subset of the product actions (or product behavior). In particular, those actions (that behavior) that are (is) wanted by the user, correspond(s) to functions.

Having these statements in mind, we will investigate the relationship between 'use' and the life-cycle of the product in the following subsection.

1.5. Use as Part of a Product Life-Cycle

Use is a phase in the life cycle of a product. In the context of this research, 'life cycle' is interpreted as the process from creation to disposal, seen from the perspective of one instance of a product. Another popular interpretation, mainly used in marketing, considers the life cycle seen from the perspective of a company. It then refers to all instances of a product, often in association with the 'consumption curve'. This curve shows the commercial performance of a product from the start of its development until its withdrawal from the market (e.g. Hubka & Eder, 1988). Typically, pre-defined subdivisions are put forward as a guideline for the distinction of life-cycle stages.



C= Cain (1969); H= Hubka (1973) as translated by Nijhuis (1984); F= Franke (1975); RO= Roth (1982)[3]; RE= Roozenburg & Eekels (1995); W= Warrell (1999

Fig. 2 Phases and sub-phases of the life-cycle process.

Figure 2 shows a compilation of phases discussed in a selection of sources. The items 'Installation' and 'Reuse' (not mentioned by Franke and Roth) were inserted at top-level, since authors referred to these as taking place before or after use. The top level is chronologically ordered. The second level shows hierarchically subordinate processes. Some of these also have a fixed chronological sequence (e.g. assembly comes after part production), but not necessarily (e.g. after repair, operation can be resumed).

[3] Franke's and Roth's term 'Herstellung' is translated here as 'creation', although it strictly means 'manufacture'. This is to avoid confusion with other authors, who consider 'manufacture' to be synonym of 'part production'.

2. Consideration of Use Processes in Product Design: the Current Situation

Three common approaches could be identified in literature that anticipate the use processes in product design: (1) focusing on 'usability' and related concepts, (2) collecting reactions from users, and (3) consideration of use as one of the phases in the life cycle. The three approaches display a strong relationship to the application of human factors or ergonomics in design. It can be illustrated with the following widely accepted definition of human factors: 'That branch of science and technology that includes what is known and theorized about human behavioral and biological characteristics that can be validly applied to the *specification, design, evaluation, operation* and *maintenance* of products and systems, to enhance safe, effective and satisfying use by individuals, groups and organizations.' (Sanders, 1988). Considering the italicized terms in the definition, *specification* and *design* correspond to approach (1), *evaluation* corresponds to (2) and *operation* and *maintenance* correspond to the more process-oriented focus of (3). The first two approaches do not only pay little attention to the process aspect of use and to prediction of changes but also, they do not rely on use-process *modeling*. Still, they are influential in the current practice of 'designing for use'. Therefore, they will be further investigated in the following two subsections., Being process oriented, approach (3)is directly related to modeling and forecasting. It is included in section 3, which covers current use-process models.

2.1. Usability and the Concepts Related to It

According to various references, optimizing products for *usability* plays an important role in creating products for various use processes. A related concept is the *use benefit* of a product, which is a pseudo-ratio between usability and the sacrifices connected to the use of a product. A third related concept is that of *user requirements*, which cover usability aspects for a specific product.

2.1.1. Basic Definitions

Usability has been defined in ISO standards Nos. 9126 (for software) and 9241. These standards provide rules of thumb for design of common operation controls for products, machines, software, etc. They cover, for instance, the preferred dimensions of a rotating knob, or the spatial arrangement of push buttons on a panel. For visual display terminals, ISO 9241-11 defines usability as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'. Li (1999) defines usability as the degree to which users are satisfied with using artifacts. Warrell (1999) states that usability focuses on the way people use the product in different situations. Keinonen (1998) discusses methods for establishing quantified 'usability indices'. One of his conclusions is that allegedly objective indices are mostly based on subjective experiences. Summarizing the foregoing definitions and circumscriptions, we can say that usability reflects the degree to which a product is optimized for use-related aspects. Improving usability is facilitated by guidelines that can be directly incorporated in the artifactual design of the product. Generally speaking, aspects or determinants of usability can be attributed to (1) suitability for the intended user population, (2) user satisfaction and user-perceived quality incorporated, and (3) suitability for use learning.

Use benefit has been defined by Dirken (1997) as a quasi-quantitative quotient. The numerator is the mathematical product of (a) the necessity of the product, (b) its frequency of use, (c) its lifetime, (d) the number of users and (e) the pleasure that people can take from the product. The denominator is the sum of (a) the effort before, during and after use and (b) the cost of the product including the cost of time and space needed to use the product. Dirken does not give units to be used for the quantities. The terms in the numerator can have any unit since they are multiplied; the denominator can possibly be expressed in terms of money.

For a specific product, the most important usability criteria are often expressed in the form of *user needs* and *user requirements* (Ulrich & Eppinger, 2000; Kärkkäinen et al., 2001; Saiedan & Dale, 2000). User needs and requirements refer to product attributes desired by the applicators (users). Together with other requirements (e.g. legal, manufacturing) they form the requirements specification for a product. To collect the basic data for quantification of the user requirements, Ulrich & Eppinger recommend the application of user interviews. Part of the interview is the description of use (process or session) by the user. User interviews call for special arrangements, especially with remote users. Eppinger does not provide a method to translate descriptions by users to requirements. Also, methods have been proposed for objective and quantitative specification of user requirements. Quality function deployment (QFD) is one of the frequently considered methods (Otto & Wood, 1999; Vairaktarakis 1999, Yoshioka et al., 1997). However, QFD does not consider user requirements in the context of the use process.

2.1.2. Determinants of Usability

As determinants of the usability of a product, various examples of use aspects are addressed in the literature. For a specific product, these aspects are usually concretized/quantified in the use requirements. Usability factors that were found in the investigated literature can be roughly subdivided into (a) suitability for a targeted user population and (b) user satisfaction.

The *suitability for a targeted user population* is mentioned in ISO 9241 and by Çakır (2000). To some extent, the other usability aspects in this listing can all be considered dependent of the user population. The following sub-aspects of user population were encountered: (a) body characteristics, (b) culture, (c) level of experience (in the sense of skill), and (d) restrictions by impairments.

The most common *body characteristics* are the anthropometric, physiological and anatomical ones. They are addressed in ergonomics-related papers about product use (e.g. Christiaans & Bremner, 1998). The body characteristics of a user determine his or her ability to interface physically with the product and the environment. *Culture* is especially gaining importance in connection with the globalization of the economy (Honold, 2000, Yeo et al., 1998). When designing products for different cultures, one has to anticipate possible differences in how users deal with a product. Li (1999) and Murdoch (1983) give examples of *user-experience* (or skill) levels for which a product may be intended. Li distinguishes novice users, average users, accidental users and expert users. Murdoch distinguishes non-captive users ('general public') and captive users ('specialists'). Learning how to use a product is part of the use process and the course of the learning process is influenced by the level of user experience as well as the 'learnability' of the product (Keinonen 1998; Li, 1999). Learning to use is part of the 'effort' determining use benefit mentioned in subsection 2.1. Harrison et al. (2001) give a categorization of *handicaps* that users can be impaired with, discussing the implications that handicaps may have in product design. Handicaps can influence the interaction with the product and the associated learning process. *Safety* of the user, and risk prevention for the user during use, are aspects of usability discussed by e.g. Weegels and Kanis (2000) and Çakır (2000). Paghini et al. (2001) give an overview of methods to take safety of both user and environment of a machine into account. The methods are embedded in a design procedure. Green (2000) points out that safety considerations are the primary motivation for the designer to investigate all possible forms of product use that can be foreseen.

User satisfaction is practically the result of a user's evaluation after a use process. 'User perceived quality' (mentioned together with user satisfaction by Çakır (2000)) is the result of evaluation by the user before the actual use. Like user satisfaction, it depends on a user's individual expectations and attitude towards a product, which is often based on experience with similar or identical products (Margolin, 1997). To express the level of user satisfaction, the *frequency of use* can sometimes be quantified. This is often done when user satisfaction is assessed as a measure for brand loyalty concerning consumables (e.g. food, disposables, rather than durables) in marketing literature (Dubrovski, 2001). Important sub-aspects of user satisfaction are user pleasure, user comfort and aesthetic appeal. *User pleasure* depends on emotions like pride, excitement, nostalgia, etc. According to Jordan (1998), who takes user pleasure as his primary viewpoint, user satisfaction and usability are even sub-aspects of user pleasure and not the other way round, as we treat it here. *User comfort* is a topic of ergonomic studies. On the one hand, comfort is determined by the atmospheric environment and the influence of factors like temperature, noise, light etc. (Parsons, 2000). On the other hand, it is determined by the direct interaction between the product and the user, strongly depending on specific population-related aspects such as anthropometry (Christiaans & Bremner, 1998). The *aesthetic appeal* of a product can be an important contributor to satisfaction as well as to perceived quality and pleasure. According to Hubka (1973), aesthetic qualities are especially important for consumer products. Aesthetics do not show a clear relationship with the time-related aspects of the use process. Although appreciation of the product's shape can perhaps be seen as a process, the related research focuses on identifying those artifactual characteristics that determine the level of appreciation. Wallace et al. (1993) present a CAD application that is capable of evaluating such (geometrical) characteristics.

It can be felt from the investigation that the various sub-aspects of usability are heavily intertwined. In addition, many of them cannot be expressed in an objective or quantitative form. Even if the overview would cover 'usability' completely, it would be difficult for a designer to anticipate and evaluate all closely interrelated aspects in a product. Although the aspects give clues on use-related features of the product, their applicability is limited since they do not provide clues about the process side of use. Consider, for instance, a designer who wants to create a product suitable for the anthropometric properties of a given user population. If the product belongs to a very common archetype, such as 'chair', the usability guidelines will be available and the designer can expect them to cover the most likely forms of use. For novel products, usability guidelines are not available. There are no tested methods to find out how use will take place, or to derive customized usability guidelines.

1.1 Consideration of Product Use in Design Based on User-Involvement

By some authors, the user involvement-based approaches discussed here are called 'feedback approaches[4]'. In most cases, the feedback given to designers not only includes how people use a product, but also the users' opinions about a product, focusing on the query if they will buy the product rather than how they will use it. Typically, user reactions are collected by marketing persons who decide what part of the knowledge is passed on to designers. Some of the approaches found in the literature are limited to 'back-casting' based on already available products (Wiklund, 1994).

McKenna (1995) discusses various methods for 'real-time marketing', which are applied before the design process, or as reviews/evaluations after the completion of certain phases in the design process. That is to say, the methods McKenna discusses are not fully integrated into the design process. Çakır (2000) discusses various forms of the so-called 'report systems'. The most common application of such systems is in large installations, such as power plants. These systems typically comprise a procedure to report cases in which user errors lead to incidents or accidents. Report systems can provide clues on how to improve future designs of installations, but they only cover the error-based, 'negative' aspects of use. He attempts to transfer the approach to pre-production designs of consumer products, shifting the focus from user errors to usability. User panels are often deployed to react on not-yet finalized

[4] 'Feedback' is interpreted here in the general sense of 'response' or 'commenting', not in the strict sense that is known from expressions like 'feedback loop' in control engineering, where output is fed back as input to an earlier step in the same process.

product designs in product-evaluation laboratories (e.g. Buur & Bødker, 2000); often done during conceptual design (e.g. Dixon et al., 1997). Reactions are often restricted to the appearance of products and consideration of use as a process is usually restricted to user-interface dialogues. Rooden (2001) investigates the applicability of conceptual artifact models, like drawings and foam models, for testing with user groups. The objective is to identify 'usability problems'. He concludes that the discrepancies between the model and the final product lead to inadequate predictions of problems with the eventual product. Involvement of experienced designers and ergonomists, assumedly familiar with the typical imperfections of conceptual models, can filter out some of the inadequacies.

Consideration of use processes in design by involvement of users is not uncommon. It is obvious, however, that successful application is often restricted to situations where the product is available in a complete or almost complete state (Green, 2000). Usually, this is the case in redesign (improving an existing product), or in detail design where realistic prototypes are available. In this stage, significant changes in the design go together with high costs.

3. Current Methods of Use-Process Modeling

Models and modeling techniques dedicated to the use process are usually embedded in a methodological framework for analysis (e.g. Task Analysis) or design (e.g. the German or European school). These models treat the actions as discrete basic entities of the process. Eventually aiming at forecasting use in computer-based design support rather than 'backcasting' as it was discussed in subsection 1.1, our focus is on characterizing the models for their potential to include knowledge in their representation form, The existing models appear to involve various schemata to capture use-related process or taxonomical knowledge:

1) *Hierarchical decomposition* refers to the capability of a model to represent actions that are subsets of other actions (Figure 3). Note that hierarchical representations of actions do not refer to the sequence in time.
2) *Arrangement of actions in time:* refers to the capability of a model to represent the structure of actions in time, also representing the progress of time, usually with arrows. The basic 'linear' arrangement in time is the most trivial, thus the most commonly included arrangement in time. The advanced models include various forms of branching (Fig. 4), such as:
   a) Divergence – one action precedes multiple (in this case only two) actions. The basic types of divergence are
      i) Divergent disjunctive ('XOR') branching and
      ii) Divergent conjunctive ('AND', parallel) branching
   b) Convergence – multiple actions precede one action.
   c) Loop (or repetition) – a combination of divergence and convergence, in which one or more actions are repeated in time.

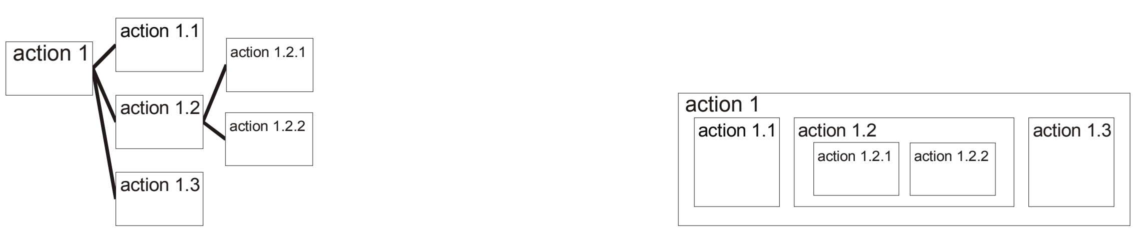


Fig. 3 Examples of visualization of a hierarchical decomposition.

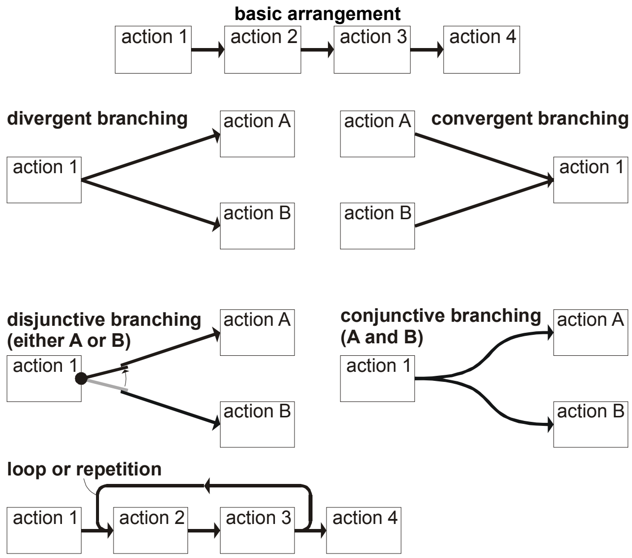


Fig. 4 Visualized examples of various forms of branching.

Additional relationships, e.g. the relations of interval algebra (Allen, 1983) ,which are expressed by terms such as *overlap, contain* and *meet*, are not yet commonly supported by use-process models. Apart from the time-relationships between actions, a quantitative *duration* can also be assigned to individual actions in some modeling techniques.

3) *Interfaces of actions:* Use-process models can be distinguished by their capabilities to represent inputs and outputs of the actions (in the form of M/E/I) and/or states of the U-P-E system before or after each action. Most models in question can only represent initial and final states of actions, and total inputs and outputs between start and finish of actions, and not the continuous changes in states or time-differentiated inputs and outputs *during* an action.
4) *Allocation of performers over actions.* Current use-process models have different capabilities to represent actions performed by the user, by the product or jointly by the user and the product. None of the models supports the representation of actions performed by the environment. Use-process models focusing on user actions typically describe so-called ‘use patterns’. Use patterns are built up from pairs of manipulations that coherently occur in recorded observations of multiple users with the same product (Roozenburg & Eekels, 1995; Otto & Wood, 1999). Obviously, such use patterns can most likely be identified as the result of the application of a user-involvement based technique (subsection 1.1).
5) *Visual representation.* An aspect of typifying use-process models can be the employed visual representation. Only three stereotypes for visual representation could be found in existing use-process models. First, the tree structure generated by a hierarchical decomposition (Figure 3, top). Second, arrangement of actions as a flow in time (Fig. 4). Third, a process graph in which one axis represents the time. Mixed representations were also found. Some tree models provide us with additional representative elements to deal with sequences in time. Some flow models employ a ‘box-inside-a-box’ representation (Figure 3, bottom) to represent hierarchical subdivisions.

3.1. Discussion of Existing Use-Process Models

I the following subsections, we discuss the use-process models in four categories based on the field of application: task analysis, user-product interface modeling, functional modeling, and life-cycle modeling.

3.1.1. Task Analysis

Task Analysis (TA) is a well-established methodological framework for describing and evaluating observed human-machine and human-human interactions in systems for professional use, i.e. for capital goods (Van Welie, 2000). This method is applied by ergonomists, system designers and system operators to create a 'task description' for system users. The constituents of task descriptions are verb-noun combinations expressing processes performed by the user. Kirwan & Ainsworth (1992) give an extensive listing of modeling techniques that can be used for task description. Some of the techniques are common process modeling techniques that are for various application fields and others are dedicated ones. The mentioned authors subdivide the techniques into six types, of which four include process-modeling techniques:

1) *Charting and network techniques* based on flow representations, showing the arrangement of actions performed by the user in time:
   a) *Input-output diagrams* focus on representing input and output. They support representation of convergence and divergence (without discriminating between conjunction and disjunction) as well as loops.
   b) *Process charts* are capable of representing linear arrangements only. They focus on a categorization of user actions based on logistic aspects (storage, transportation etc.). The so-called *'user-must actions'* model introduced by Chakrabarti (1999) is practically identical to the process chart. It is aimed at eliminating actions for which a system becomes too dependent from the user and, therefore, too unreliable.
   c) *Functional flow diagrams* are capable of representing disjunctive and conjunctive divergent branching, as well as convergent branching. Hierarchical decompositions are handled through a numbering system.
   d) *Information flow charts (also known as decision-action diagrams)* support disjunctive divergent branching, loops, and states of the system. Representation of the latter is supported only if serving as conditions for disjunctive divergent branching.
   e) *Critical path analysis* (also known as *critical path method* or CPM) supports conjunctive divergent branching and convergent branching as well as relationships from interval algebra (Smith & Morrow, 1999). Since its focus is on lead-time calculation, it also supports assignment of quantitative durations. Neither interval-algebra relationships, nor durations are included in the flow-based visual representation that is employed in CPM.
   f) *Petri-nets* focus on representation of system states between actions. They support the representation of conjunctive and disjunctive divergent branching, convergent branching, and loops. An example of an application to the use process of a consumer product, which also includes interval-algebra relationships, can be found in Suto et al. (2000).

2) *Hierarchical task analysis*, includes hierarchical subdivision of actions. Contrasting flow-based task-analysis methods, it visualizes the process in a tree structure that can show both hierarchical decomposition and linear arrangements in time. The tree can be extended with flow elements to support disjunctive divergent branching, convergent branching and loops. The states of the system can be included if they serve as conditions for disjunctive divergent branching.

3) *Operational sequence diagrams* appear in three forms. Two of them are process models: the *basic operational sequence diagram* and the *partitioned operational sequence diagram*. A basic operational sequence diagram is very similar to a process chart. Partitioned operational sequence diagrams are more powerful in terms of knowledge-capturing capabilities. Kirwan & Ainsworth (1982) discuss the *job process chart* as a specific type of partitioned operational sequence diagram.

The job process chart is the only task-analysis method that, apart from user actions, explicitly distinguishes actions performed by the product. It supports disjunctive divergent branching, convergent branching and loops. It is also capable of representing information inputs and outputs as well as states of the system if they serve as conditions for disjunctive divergent branching.

4) *Timeline analysis* is a technique to model linear arrangements of actions in time. It is visually represented by bars rather than by blocks and arrows and it allows for quantification of durations by means of addition. The addition of times may include extra knowledge about statistical variance.

3.1.2. User-Product Interface Modeling

Process models of user-product interfaces are typically applied in the design of non-physical products (especially software). The same techniques can be applied to the interaction between users and service-providing organizations, or to the employees and procedures in companies (e.g. Zimmermann & Bridger, 2000), and also to interaction between users and physical products. Buur et al. (1991) apply a use-process specific *decision tree* to model how a photo-copying machine is operated by its user. Although its visual appearance strongly resembles the hierarchical tree structure in Figure 3, the decision tree actually represents an arrangement in time. It shows a flow of divergent actions without distinguishing between conjunctive and disjunctive branching. It does not support convergent branching, does not deal with states, inputs and outputs, and does not clearly distinguish between user actions and product actions. To more specifically address the relationships between actions within a use process, a process structure (a functional model discussed in subsection 3.1.3) and *state transition structures* are used. The latter one has also been applied by Hansen (1996) in a model representing the processes carried out by a tumble dryer and its user. A state transition structure is capable of representing states between actions and supports divergent branching, convergent branching and loops. For divergent branching, no explicit distinction is made between conjunction and disjunction. Unlike the aforementioned Petri-nets, state transition structures are strictly sequential and limited to a global notion of state, whereas Petri-nets can handle distributed states and concurrency.

3.1.3. Functional Modeling

Functional modeling (FM) is propagated by the European schools of design, one of the most customary 'families' of methodological frameworks for design of physical artifacts. FM does not explicitly provide use-process modeling techniques. Yet, it is closely related because the functional models it deploys apply to the same stage of the product life-cycle as early use-process modeling. In a sense, FM is complimentary to TA: functional models typically use verb-noun expressions to model behavior required from the product rather than processes carried out by the user. Like TA, FM primarily focuses on capital goods rather than consumer durables.

The most elementary model in functional modeling is the *function structure* (FS) (Pahl & Beitz, 1988). It is a flow-based model capable of representing convergent branching, divergent branching (the latter without distinguishing conjunction and disjunction), loops and inputs and outputs separated into material, energy and information. After the development of the methodological framework of FM in the 1970s, extensions and modifications have been proposed in the related literature. The 'network activity diagram' suggested by Otto & Wood (1999) differs from the FS only in that it represents actions performed by the user rather than by the product. It is used to capture use patterns for consumer products. In a proposed approach for redesign of an existing product, Otto & Wood combine the use of the network activity diagram of a use process with a FS but they do not elaborate on possible connections between the two representations. Some of the modifications proposed in the literature implicitly combine user-initiated and product-initiated processes in a merged representation (e.g. Otto, 1996; Erens & Verhulst, 1997). Conversely, Buur et al. (1991) present a ‘process structure’ in which they explicitly distinguish actions performed by the user and actions performed by the product. A similar approach can be found in Janhager (2001).

Warrell (1999) addresses the issue of allocation of performers by augmenting the functional language. His ‘process modeling view’ includes usability aspects in product functions. His ideas bear similarities to those in value analysis (VA), where the function description may also contain passive and unremitting verbs, such as to keep, to support, to realize, to facilitate and to guarantee. (Miles, 1961; Gasthuber et al., 1991; Fowler, 1990). In VA, the verb in a function description must be transitive (i.e. taking direct objects in a grammatical sense (Akiyama, 1991), whereas FM uses the stricter limitation to active verbs (transitive verbs expressing that the direct object is changed by the subject). VA employs product functions (purposeful part of behavior or actions) from the perspective of use value rather than from the technical viewpoint that is employed in FM. VA applies hierarchical decomposition in a *function tree.* Function trees that keep closer to the FM concept of function appear in the function-behavior representation language presented by Mizoguchi & Kitamura (2001). They are created from input-output models of existing products to facilitate computer-supported search for alternative design solutions.

3.1.4. Life-Cycle Modeling

Another group of use process models have been developed as part of descriptions of the product life-cycle. Dedicated use-process models have been derived as well. the so-called life-cycle tree or process tree (Nijhuis, 1984; Roozenburg & Eekels, 1995) is often used for representing the life cycle in

preparation of use process	1. walk to product
	2. observe presence of product
	3. reach for the product
	4. pick up product
	5. relocate product
	6. put product in working position
actual use process	7. make product ready for use
	8. connect accessories
	9. insert input materials
	10. choose and adjust program
	11. switch product on
	12. ascertain that product is operating
	13. observe progress/results
	14. modify/control the process/product
	15. interrupt or discontinue operation
	16. remove output
	17. detach and remove accessories
conclusion of use process	18. prepare product for storage
	19. pick up product
	20. relocate product
	21. put away and store product

Fig. 5 Use process according to Dirken (1997) (translation by the author). The sub-processes connected by arcs are supposed to be reversed counterparts of each other.

the problem-definition stage of design. The process tree is a hierarchical representation of the global life cycle, decomposed into sub-processes. Sub-processes of the same parent process are usually arranged in an assumed chronological sequence, hence representing linear arrangements of actions in time. Most process trees contain both user actions and product actions without explicit discrimination. The same representation is used for modeling a part or an episode of the life cycle, as is often done for production processes (e.g. Feng & Song, 2000, Murdoch, 1995; Pahng, 1999). As an aid to determine product-use cost, Dirken (1997) introduces a use-process model showing a two-level tree structure (Fig. 5). The model is intended to be a generic representation of product-use processes, but Dirken admits that the model is incomplete. The 'life-cycle process model' (Van der Vegte et al., 2001a) is derived from the concept of the process tree. It is covers the complete life-cycle and supports the representation of inclusive divergent branching, convergent branching and loops, inputs, outputs, states, as well as differentiation between user actions and product actions. In Van der Vegte et al (2001b), a 'unified description of product-related processes' is proposed for modeling life-cycle processes on a set-theoretical basis. It focuses on representing states, and it is capable to include continuous transitions. It also supports conjunctive divergent branching, convergent branching and interval-algebra relationships. The model does not rely on a visual representation, but continuous changes of states can be displayed as a function of time in a graph.

Table 1. Overview of use-process models as found in the investigated literature.

F: *full support*
L: *limited support*
C: *combined support for features in adjacent columns without individual distinction*

			arrangements in time											allocation of action		primary visual representation		
		hierarchical decomposition	linear	disjunctive divergent branching	conjunctive divergent branching	convergent branching	loop	interval-algebra relationships	duration	inputs	outputs	states	continuous transitions	to user	to product	tree	flow	graph with time axis
Task Analysis (TA)	charting and network techniques																	
	input-output diagram		F	C		F	F			F	F			F			F	
	process chart		F											F			F	
	functional flow diagram	L	F	F	F	F								F			F	
	information flow chart		F	F		F	F					F		F			F	
	critical path analysis		F		F	F		F						F			F	
	Petri-net		F	F	F	F	F	F	F			F		F			F	
	hierarchical task analysis	F	F	F		F	F							F		F		
	operational sequence diagrams: job process chart		F	F		F	F			F	F	F		F	F		F	
	timeline analysis		F						F									F
User- product interface modeling	decision tree		F	C										C			F	
	state transition structure		F	C		F	F					F		F	F		F	
Functional modeling	function structure		F	C		F	F			F	F				F		F	
	network activity diagram		F	C		F	F			F	F			F			F	
	merged representations (Otto, Erens)		F	C		F	F			F	F			C			F	
	process structure		F	C		F	F			F	F			F	F		F	
	function tree (value analysis)	F													F	F		
Life-cycle modeling	'regular' process tree	F	F											C		F		
	life-cycle process model	F	F		F	F	F			F	F	F		F	F	F		
	'unified description of product-related processes'		F		F	F		F	F			F	F	L	L			F

3.2. Summary of the Characteristics of Existing Use-Process Models

Table 1 gives an overview of the surveyed existing use-process models with supported knowledge-inclusion attributes. A model that is able to represent all features of a use process has not been found. The reason is that the current models all appear to be based on general process models, which do not capture sufficient knowledge about the features of the user, the product and the environment in an explicit form. For the representation of general processes, the purely process-related aspects are essential. However, use processes are different in that sense that they require explicit handling of the background knowledge about how and why interaction between the three actors U, P and E involved in a use process takes place. This is exactly what is missing from typical process models. Currently, this type of information is already considered and modeled by various human, product and environment models. Therefore, the next section will study the models of the actors, with the aim of clarifying what knowledge is included in these models and how the various actor models could be combined with non-specific process models.

4. Modeling the Three Actors of the Use Process

In this review of models and modeling techniques for users, products and environments we concentrate on techniques that are relevant to the use process in the sense that they include sufficient knowledge about attributes, features and behaviors of users, products or environments. Typically the modeling techniques for *products* and *environments* are not distinguished. Especially when discrete objects are involved as environment, products and environments can be modeled with the same *artifact modeling* techniques. Nevertheless, there are specific environment models for continuums – in particular for air and water, which determine the macro- and microclimate around products and users. Although modeling climatic environments is important from the use of a product, climate and climate models are not considered for this research. Models of the *user* deserve special attention. Since models of 'users' as such can hardly be found outside the context of models already discussed in section 3, our investigation is extended to 'models of humans' We attempt to find those techniques that are applicable to modeling external interaction of humans with products and with environments as it takes place during the use of products.

4.1. Modeling Artifacts from Various Aspects

Since the early 1960s, several approaches have been proposed for modeling artifacts. What is common in all approaches is that they focus on one or on a limited number of aspects. That is the reason why these artifact models have been named after the aspects so as geometric models, assembly models, system models, function models, feature models, analysis models and so forth. An overview of commonly used models is given in Horváth (1996). Since other reviews are also available, below we only briefly summarize those characteristics of the common artifact models that have significance for modeling the product and/or the environment in use. We distinguish abstract artifact models and concrete artifact models.

Abstract artifact models do not intend to reflect the actual apperance of the artifact. According to Rusák & Horváth (2002), they describe the shape with less information than needed to completely represent the nominal shape – for instance by focusing on its structure. Illustrative overviews of such artifact models, together with some process models, can be found in Murdoch (1995) and Andreasen et al. (1996). Examples are organ structures, assembly structures and configuration models, but also informal representations like manual sketches and foam models. The purpose is to support exploration of ideas about the structure of products during early stages of design. Consider for instance a premature vehicle design for which it has only been defined that it consists of a cabin with three wheels underneath. An abstract artifact model can be used to specify this configuration without paying attention to the diameters of the wheels, the shape of the cabin etc. Models in this category usually do not show specific references to the use process, but they can be used to support design for use in early stages of design (Rooden, 2001).

Concrete artifact models intend to reflect the actual appearance, or the actual properties, of the artifact by involving at least the same amount of information as needed for a complete geometric model of a nominal shape. Traditionally, artifacts were represented by 2D drawings and by 3D physical models. These traditional models are typically applied in embodiment and detail design. However, concrete conceptual models also exist. Opposite to abstract conceptual models, they are derived by simplification of the artifact rather than abstraction. Since the 1960s, the concrete artifact models are usually created by various CAD systems, as discussed in Shah & Mäntylä (1995) and Horváth (1998). Application of CAD also made it possible to work in 3D without the necessity of employing physical models. The most commonly known categories of artifact models signifying the present state-of-the-art in CAD can be:

- synthesis models, including *geometric models* (solid models, surface models and feature models) and *assembly models* (structural assembly models and mechanical tolerance models);
- simulation models, including finite-element analysis models, kinematic simulation models, and product costing models.

Synthesis models are – eventually – used to provide a specification for production: dimensions of parts, instructions for machining equipment, part-to-part interfaces in assemblies, etc. In designing they replace the traditional representations and they facilitate defining the way a product is manufactured. Synthesis models are used not only for representation but also used for visualization purposes as well as input data for simulation models. Advanced visualization models make it possible to render a more realistic impression of users and objects in the environment. There is a potential to include knowledge about the behavior of the artifact. Actually, behavior is what brings the aspect of process or change in artifact modeling. This means that the conventional artifact models are gradually being converted to simulation models of all kinds. Artifact models with simulation capabilities are directly relevant for use-process modeling.

4.1.1. Artifact-Simulation Models: Simulating Behavior of the Product and the Environment

In artifact-analysis models, the conventional approach to simulation modeling is to devise a set of symbolic equations specifying a particular situation or a class of situations (Bryant et al., 2001). Typically, the artifact system and the situation are *idealized* to avoid complicated equations. By solving the equations analytically in the time domain, the course of a process can be predicted. If an analytical solution is unavailable, simplification of the equations is needed, or numerical approximations can be applied.

One frequent reason for unavailability of analytical solutions is complexity. Products, environments, and product-environment systems are usually complex and therefore difficult to simulate, even after idealization. Another complexity issue is that in our real world, multiple physical phenomena apply at the same time, although not all of them require the same attention at a given moment in time. It is for this reason, as argued by Roozenburg & Eekels (1995), that it is impossible to simulate the behavior of the complete system in one model. From an epistemic point of view, the principle of reductionism becomes governing, not only in modeling, but also in investigation of the reality. One of the mathematical consequences of increasing complexity is that nonlinearities in the system behavior can no longer be neglected. Research efforts are increasingly directed towards enhanced simulation techniques that are able to deal with non-linear, or even *highly non-linear* systems. With the increasing power of computers, *numerical methods* have gained popularity. The most straightforward numerical methods are typically purely mathematical recipes for solving particular types of 'difficult' equations, for instance the Newton-Raphson method for algebraic equations and the Runge-Kutta methods for differential equations (e.g. Riley et al., 1997).

Other numerical modeling techniques do not predict the course of a process by solving equations that apply to an idealized system, but based on a *discretized* representation of the system.

Discretization takes place by building up artifacts from stereotypical solution elements. The elements carry knowledge about a certain behavior, e.g. about deformation as a function of external forces or about the way incoming energy is processed (transmitted, transformed, stored etc.). Usually, the behavior knowledge is a linearized simplification of the actual physical behavior. Some widely applied simulation techniques based on discretization are bond graphs, finite-element modeling and mass-spring modeling.

Bond graphs simulate time dependent behavior of multiple-component artifact systems. Simulation is based on energy flows (e.g. Redfield & Krishnan, 1992, Finger et al., 2001). The components of the artifact system are represented by basic physical characteristics, e.g. 'resistance', 'capacitor' or 'transformer'. Analogies between different domains of physics allow for using the same building blocks throughout hybrid systems, i.e. systems built up from mechanical, electrical, hydraulic, etc. components. A building block can represent the function of a component (e.g. 'to transform') but also unwanted secondary behavior (e.g. friction). For electrical and hydraulic systems, the components of a bond graph correspond more directly to artifact components than for mechanical systems (Van der Vegte, 2000). Zeid & Overholt (1995) describe a method to build complex models of multibody mechanical systems using bond graphs. Margolis & Shim (2000) and Gawthrop & Ronco (2000) present similar non-linear applications of bondgraphs, to be applied to vehicles and mechatronic systems, respectively.

Finite-element modeling (FEM) is based on an assumption of energy minimization in the artifact. It was originally intended for mechanical stress analysis in static situations (Zienkiewicz & Hollister, 1965). Later extensions of FEM cover dynamic behavior and behavior in areas other than mechanics, such as heat conduction, electric and magnetic potential and fluid flow (Zienkiewicz & Taylor, 2000). Some typical *non-linear* FEM applications are friction and contact with arbitrarily shaped rigid surfaces (e.g. Saran & Wagoner, 1991), elastoplasticity in large deformed solids (e.g. Kim & Kim, 1994) and rubber parts with complex geometrical shapes (e.g. Antoun et al., 1995). A promising advancement towards integration of multiple physical phenomena in simulations is *multiphysics analysis*. The conventional approach to multiphysics problems is to formulate and solve case-specific equations (e.g. Doltsinis, 1997), but most of the more recent approaches are based on FEM techniques (e.g. Bailey et al., 1998). Mahoney (2000) reviews some commercial software packages for FEM-based multiphysics analysis that are already on the market.

Mass-spring particle modeling can be applied to simulate mechanical behavior of deformable objects (Terzopoulos et al., 1987). It is based on Euler's differential equations for spring-damper systems. This modeling technique is extensively applied in *computer graphics (CG)*(Cerezo et al., 1999). In the 1990s, most of the research on mass-spring models concentrated on animation of cloth-like materials, i.e. quasi-2D artifacts (Provot, 1995; Baraff & Witkin, 1998; Hauth & Etzmuss, 2001). Recently, application to 3D solid objects is coming more into focus (e.g. Bourguignon & Cani, 2000; McDonald, 2001). Although mass-spring particle modeling lacks the non-mechanical extensions known in FEM, it produces more realistic, real-time mechanical simulations (Jansson & Vergeest, 2000). FEM focuses on reaching the state of minimum energy at the end of a simulation interval. In-between-effects, for instance oscillations, are ignored.

An entirely different approach to artifact-behavior simulation, with equations sometimes only playing a minor role, can be found in the application of *artificial intelligence* or AI-techniques. Unlike the above numerical techniques, most AI-based techniques are not yet widely applied in engineering – they are still studied by researchers. Part of the behavior that is governed by equations in other techniques is controlled by rules stored in knowledge bases, making *qualitative* simulations possible as well. A well known example is the application of qualitative reasoning (Forbus, 1984). Other common

AI concepts applied in artifact-behavior modeling are agents (e.g. Mah et al., 1994), neural networks (e.g. Masini et al., 1999) and ontologies (e.g. Horváth et al., 1998). The latter two publications propose combinations of AI techniques and equation solving.

4.2. Modeling Humans (users) from Various Aspects

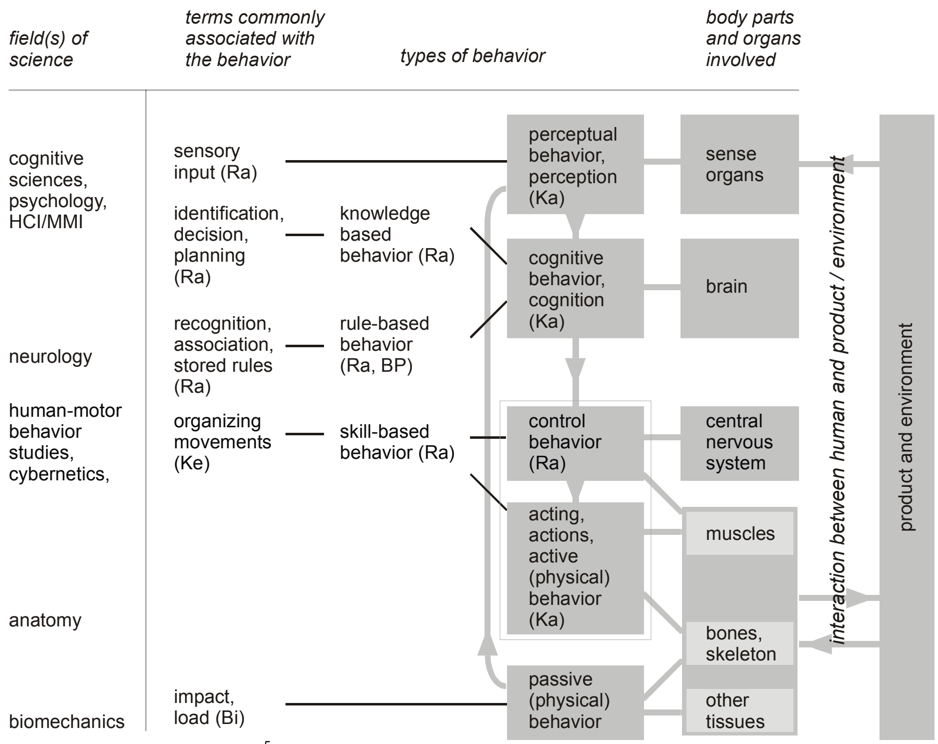
Most models of humans are rooted in a field of science that is dedicated to specific aspects of humans. The background is often purely (para)medical rather than design-related, e.g. psychology, neurology, anatomy, physiology, physiotherapy or traumatology. Other models are rooted in engineering sciences. Although these more technical models can be applied in a (para)medical context, some of them are also presented in a design-related context: anthropometric models, models used in cybernetics, CG, biomechanics, manual materials handling and HCI/MMI. Since the various fields of science and the applications of the models are heavily intertwined, they cannot be used as a guideline to categorize or to characterize the models. For this review, we subdivided models of humans into four categories. Although there are overlaps, human models tend to have a basic orientation towards one of the four:

1. *equation-based* or purely mathematical models, which are usually case-specific;
2. *geometric and assembly models* of the human body in various postures: typically anthropometric manikins and avatars;
3. *models based on discretized system representations,* such as FEM models, bond graph models and mass-spring models
4. *models based on artificial-intelligence (AI) techniques*, such as neural networks and agents.

As a consequence of our focus on use as a process, we generally ignored purely static models of humans, except where a specific type of model can be employed both statically and dynamically. This is notably the case with anthropometric manikins and FEM models.

To characterize the models discussed, we evaluated the potential to cover knowledge of the use process. We took the so-called *input-throughput-output models* of humans as a starting point. These cognitive models are often used to describe user behavior, distinguishing subroutines or sub-behaviors that can be allocated to certain parts of the body. To obtain a complete picture of human behavior, input-output-throughput models from various sources have to be compiled, since they appear to supplement each other. Fig. 6 depicts our effort to obtain a complete view of sub-behaviors from existing sources. The first column roughly indicates the fields of science covering particular sub-behaviors. The second column indicates common terms related to the items in the other columns. Both the first and the second column are included for orientation only. The third column shows the subdivision into knowledge-based, rule-based and skill-based behavior that is commonly used in HCI/MMI design, where physical human-product interaction is largely ignored. This subdivision was introduced by Rasmussen (1986). Rule-based behavior is highlighted by Brown and Perry (2000) as a common cause of misconceptions in product design. They argue that designers fail to anticipate forms of unintended use by assuming that users always follow the default rules.

The subdivision into perception, cognition and action in the fourth column is often mentioned in the context of industrial design, e. g. by Kanis (1998). This subdivision can be completed with two types of behavior from other sources that it does not cover: control behavior and passive physical behavior. Control behavior corresponds to Rasmussen's skill-based behavior. It refers to unconscious control that is exerted by the central nervous system to direct the movement of body parts. Control behavior is studied in the fields of human-motor behavior studies (HMB) and cybernetics. Passive physical behavior, i.e. movement and deformation of body parts as an effect of external influences, is the leading topic in the field of biomechanics (e.g. Huston & Passerello, 1982; Hughes & An, 1999; Therrien & Bourassa, 1982). The fifth column in Fig. 6 shows the body parts and organs involved in the various sub-behaviors. Simulations of human behavior commonly indicate which sub-behavior is



Bi = various sources from biomechanics[5]; BP = Brown & Perry, 2000; K = Kelso, 1982; Ka = Kanis, 1998; Ra = Rasmussen, 1986.

Fig. 6 Input-output-throughput model of the human in the use process compiled from various sources.

covered by referring to body parts. The interaction with products and environments takes place through specific body parts and organs as is indicated on the right.

A dissection of sub-behaviors into (1) perceptual behavior, (2) cognitive behavior, (3) control behavior, (4) active physical behavior and (5) passive physical behavior appears to give a reasonably complete picture of human behavior in interaction with products and environments. In the following subsections, we will use this categorization to map the areas of knowledge covered by models of humans. We will assume that the level of detail provides sufficient insight in the capacities of the various models. For instance, we could have further subdivided perceptive behavior into visual

[5] For specification of the references, see the discussion of biomechanics towards the end of the subsection.

perception, aural perception, tactile perception etc., but for this inventory, the knowledge that a particular model covers (aspects of) 'perceptual behavior' is supposed to be sufficient.

4.2.1. Equation-Based Models of Humans

In the context of this review, equation-based models are models that purely rely on equations. This implies that the standard way of modifying a model is to directly modify (variables in) the equations and not to modify a superimposed model, e.g. a discretized model of a human. Equation-based models are typically created to solve problems that are limited to specific cases. From the 1970s on, systems of equations from Newtonian dynamics have been applied to develop models of (parts of) humans in the area of biomechanics (e.g. Huston & Passerello, 1982, Hughes & An, 1999). An example of research into human interaction with products (sports equipment) can be found in Therrien & Bourassa (1982). Here, the case-specific character of mathematical models reveals itself by only covering specific singular events in the interaction, e.g. the effect of external impact on a human head wearing a protective helmet. The examples do not deal with a use process. In biomechanics research, this type of simulation is also strictly analytical–i.e. aimed at finding explanations for observed phenomena. A closely related field of research is manual materials' handling, which considers a specific form of product use: the human task of lifting a product and moving it to a different location. Analytical studies made it possible to formulate equations for prediction of injuries. Acceptable situations can be identified based on simplified parameters, such as horizontal and vertical lifting distance, and main dimensions of the load (product) (Ayoub & Woldstad, 1999). The only decisive criterion here is the risk of lower-back injuries.

Another area of research where mathematical models of humans are developed is perceptual control theory (PCT) (Bourbon & Powers, 1999). PCT focuses on modeling control behavior of humans and animals, including physical movements (Powers 1999a). The theory can also be used to program algorithms that implement 'natural' control mechanisms in artifacts (Powers, 1999b). Job et al. (1999) present an example of equation-based modeling of a subsystem of visual perception, namely the induction of electric current in the retina. It is a typical example of an equation-based model dedicated to a very specific case. It can be used to diagnose certain functional abnormalities at the retina, and it does not appear to bear relevance to use-process modeling.

4.2.2. Geometric and Assembly Models of Humans

Most of the models discussed here are a combination of geometric models – where the detailed geometry of individual body parts, such as hand, head etc. are concerned, and assembly models – where the overall structure of limbs, joints etc. is concerned. In their purest form, these models represent the physical appearance of users. Anthropometric manikins are the most common models in this category (Hoekstra, 1996, Jung & Kang, 1995). In design, they are typically applied as an aid in matching the dimensions of product models to external human dimensions. The development of static quantitative models for this purpose has reached the stage of maturity. Various software packages that can be used to integrate manikin representations in CAD are commercially available, and academic research in this field is still going on. Most of the anthropometric models are static, but a growing number of software packages provides us with animation capabilities to study transitions between postures. The majority of the animations concentrates on kinematics (e.g. Williams & Medland, 2001). The predictive value is limited to identifying the movements allowed by geometrical constraints. An animation technique that also considers the forces involved (kinetics) and human control behavior is presented by Park and Fussell (1997). They describe simulation of motion control by applying nonlinear equations derived from Newtonian dynamics. The objective is to obtain animated movements that are more realistic. The 'brain commands' that represent the manikin's cognitive behavior are issued by the user of the animation software. It has to be noted here, that this typical emphasis on ‘guided’ beings in CG animations is shifting towards ‘autonomous’ beings (Cerezo et al., 1999). As a result, actual *simulations* are also emerging in this field, using AI modeling techniques. They are discussed in subsection 4.2.4.

Equation-based dynamic simulations with anthropometric manikins are also employed for other purposes than animation. Kingma et al. (1996) apply anthropometric models to predict how the mechanical load on body segments varies during lifting tasks. Sloan & Talbott (1996) describe a forensic application of a 2-D manikin to simulate common accidents involving falls. This approach seems to be applicable in specific product-related situations where the usability aspect of safety is involved.

Other recent forms of anthropometric manikins are used in virtual reality (VR), and collaborative virtual environments (CVEs). Here, manikins appear as full or partial *avatars*. VR allows a real person, the user of the VR system, to interact with virtual products, which only exist as assembly models. The system user controls the movements of the guided avatar and receives tactile and/or visual feedback from it as it interacts with the product. The interaction is part of a use process. Yet, contemporary VR hardly offers added value compared to regular manikins. The virtual use process is controlled by the system user’s real-time actions. Hence, the process knowledge about user behavior remains in the mind of the user. Knowledge in the model remains limited to object properties. The geometric model represents the avatar in order to allow tactile feedback by means of collision detection (e.g. Baciu et al., 1998). Inclusion of knowledge about product behavior is missing in most of the current VR systems, but recent developments may bring radical changes (e.g. Hummel & Girod, 1999).

In CVEs the emphasis is on establishing person-to-person contact between the participating avatars controlled by the users they represent. The objective is to enable people at different locations to work together in a virtual environment (Honda et al., 1999). This requires extension of VR capabilities in that avatars do not only receive feedback about the environment but also about each other. Feedback is not only visual, but also aural, to make communication through speech possible. Tactile aspects are usually less important in CVEs. A CVE can be used to simulate use processes of remote users related to particular products.

Summarizing, we can say that models of the physical appearance of users are already effectively deployed in the consideration of the use of products during design. The most advanced predictive applications include control behavior as well as active and passive physical behavior. Perhaps these simulations can be enhanced if they can be fed with knowledge about cognitive and perceptive behavior. This may allow manikins/avatars to operate independently from real persons employing real-time control. For a matter of fact, the distinction between manikins and avatars seems to be arbitrary, and largely depending on the research background of a particular publication.

4.2.3. Models Based on Numerical Methods Based on Discretized Representations of Humans

In modeling human behavior, numerical models based on discretization are gaining attention. We found examples of the application of three techniques also known from artifact modeling: bond graph modeling, finite-element modeling and mass-spring systems modeling.

Bond graphs are not frequently used in models of humans. Pop et al. (1999) apply them to create a partial model of the human body. The model represents highly nonlinear control behavior based on Newtonian dynamics. It is used to simulate corrective responses of the human body to unexpected perturbations during walking. In product use, similar bond graphs might be useful where corrective responses are likely to occur during the interaction with products or the environment.

FEM simulations have become popular in biomechanics from the second half of the 1970s. Chow & Odell (1977) apply a static FEM model to analyse body deformations of sitting persons to aid the design of cushions to prevent decubitus ulcers. Moes (2000) presents a similar static application aimed at improvement of seating comfort in product designs. Dynamic finite-element models are less common in biomechanics, although the number of applications is growing. Mostly, there is a strong focus on passive behavior of particular parts or sections of the human body. For instance, Bandak et al. (2001) apply a dynamic finite-element calculation to study the mechanisms of impact injury on the human foot. Since a product may also act upon the human body during its use (Fig. 1 in subsection 1.4), such models can also be useful in use-process modeling. Koch et al. (1998) make the connection with active physical behavior by including an equation-based model of muscle contraction in their dynamical FEM model of facial-expression forming.

Mass-spring models of humans are typically found in CG animations. The most advanced application in human modeling up until now is presented by Porcher Nedel & Thalmann (2000). Although the muscles–normally the 'motors' of human actions–are included in the models, their behavior is determined by a passive model. With the intent to achieve realistic dynamical rendition of the body in 'guided' animations, movements are imposed on the skeleton, with the muscles following. The approach suggests that simulation of the actual workings of muscles can be left out in those human simulations where only external aspects are concerned. This would also apply to interaction with products and environments in a use process. Yet, the reliability of Porcher Nedel & Thalmann's model has not been verified by comparison with real humans. Some similar applications of mass-spring models, mostly applied to animations of animals and artificial life forms, are discussed in a survey by Cerezo et al. (1999).

4.2.4. Human Models Based on AI Techniques

AI techniques in human modeling are mostly used for the upper, non-physical regions in Fig. 6 . We found examples of the application of two techniques in particular: neural networks and agents.

Neural networks appear to play a significant role in cognitive simulation models. Neural networks can strictly be considered discretized models of human body components, i.e. nerves and synapses, but usually there is no direct relationship with such components. Typically, known examples restrict themselves to a specific aspect of behavior in a specific domain. An example is steering behavior of airplane pilots in wind shear (Martens, 1998). Although the simulation output is in the form of physical (mechanical) quantities, i.e. position and speed of a plane, the behavior of the pilot is only regarded from a decision-making point of view. The effect of decisions is directly expressed as the physical state of the plane, while human physical output leading to the behavior of the plane is skipped. Likewise, the physical state of the plane forms direct input to the decision-making process, skipping perceptive behavior as well. Most decision-making applications of neural networks are aimed at *replacing* human decision making rather than predicting it (e.g. Ishibuchi & Nii, 1998). An interesting observation is, that in some cases *decision trees,* which were also mentioned as descriptive use-process models (subsection 3.1.2) are used as an initial modeling step for the networks (e.g. Setiono & Leow, 1998). Neural networks are also applied to simulate human control behavior in the area of cybernetics. Kim & Hemami (1998) simulate mechanical behavior of the head and torso reacting on input from the central nervous system with highly nonlinear differential-equation systems. The behavior of the central nervous system is simulated by a neural network. It acts on the output of what is called a 'desired trajectory generator', representing the brain that issues the decision to carry out a particular movement. This higher-level cognitive behavior is left out of the simulation.

Table 2. Overview of the coverage of human-behavior types by the human models found in the investigated literature

		perceptual behavior	cognitive behavior	control behavior	active physical behavior	passive physical behavior
Equation-based models		X		X	X	X
Geometric/assembly models	(manikins, avatars)			X	X	X
Structural numerical models	bond graphs			X	X	
	finite-element models				X	X
	mass-spring models				X	
AI-based models	neural network-based models		X	X	X	
	agents-based models	X	X	X	X	

Human-behavior modeling based on *agents* is becoming increasingly popular in CG simulations. One of the first significant efforts in this area was the 'Jack' project by Badler et al (1993). 'Jack' is a comprehensive manikin-like human model intended for human-factors analysis. Its most visible output is its active physical behavior, which is governed by equation-based models. The most significant novelty is that it also includes a limited implementation of perception, cognition and control behavior based on agents. In essence, 'Jack' is still a guided animation: a system user has to control it with subsequent commands describing simple actions. Bordeux et al. (1999) present a model of human visual perception based on agents as part of a human simulation model that is intended to act more autonomously. Perception is simulated by agents acting as filters, passing through whatever information from the environment is needed for decision-making. The model also includes cognitive elements, such as short-time memory of perceived objects, searching the environment for objects etc. Jung et al. (1994) present an agents-based simulation technique for human motion planning through spaces populated with objects. It practically covers cognitive behavior, control behavior and active physical behavior. Where motion is concerned, the model is explicitly restricted to kinematics; the kinetic feasibility of results has not been verified. Like in the aforementioned neural-networks model of pilot behavior, perceptive behavior is left out of the simulation, although the presence of perceived objects is taken into account.

4.2.5. Summary of the Characteristics of Human-Modeling Techniques

Table 2 gives an overview of the human models discussed in the previous subsections and their coverage of the human 'behavioral chain' depicted in Fig. 6.

Taken together, the models seem to offer a reasonably complete coverage of the various subtypes of human behavior. Yet, we have to take in mind that the one-level categorization into sub-behaviors can only give an impression of the types of behavior covered. With the limitations of this simplification in mind, we can summarize the capabilities of existing human models as follows:

- The four categories of models show significant overlaps. Apart from the purely equation-based models, most models incorporate contributions from other categories. Geometric and assembly models are mostly supported by equations. Discretized models are supported by equations and a geometry and/or assembly structure. Models with AI components may contain elements of all of the three other categories. The categorization is disputable: for instance, one may argue that a model like 'Jack' is a manikin or avatar. However, since it contains AI elements and AI-based models appear to represent the highest level of sophistication in human modeling, we chose to categorize 'him' as an AI-based model.
- None of the models or modeling categories covers all subtypes of human behavior. Considering *individual* models, some of the manikins/avatars and agents-based models from the field of CG animation provide the highest level of integration, covering control and active physical behavior combined with either cognition or passive physical behavior. Considering the modeling *categories*,

it appears that agents-based techniques cover the widest range of sub-behaviors. We did not find examples of agents-based techniques covering passive physical behavior.

- Several integrated simulation techniques simply skip some of the sub-behaviors in the behavioral chain (Fig. 6) and substitute the result of those behaviors by a straightforward assumption. The two typical examples are: (1) Perception is skipped: it is assumed that everything that can be perceived is known to the brain; (2) active behavior of muscles is skipped. It is assumed that if cognition and control directly command the movements of the skeleton, the result for the outside world is the same. We did not find indications that the validity of such assumptions has been verified by comparison with actual human behavior. This may make the models in question vulnerable when it comes to predictive value.
- In 'guided' animations, cognitive behavior is typically skipped, and replaced by the decisions of the user of the animation system.
- In the current state-of-the art in human simulations in CG, the correspondence to the behavior of actual humans has not yet been checked. If these techniques are used to anticipate product use, this issue will have to be resolved first.

Considering the combined coverage of human behaviors by the models, a fully integrated simulation model that can also interact with products and environments in a use process seems to be pending. Still, many of the discussed techniques only apply to the behavior of a particular part or detail of the body in a particular predefined situation. Considering the apparent complexity and nonlinearity of the models needed, this is not surprising. For most scientific research purposes, it seems sufficient to give a proof of ideas related to a detail rather than to develop a thoroughly verified overall solution.

4.3. The Value of Actor Models and Simulations in Forecasting the Use Process

The review of actor-modeling techniques in this section made it clear that through the various simulations, these techniques cover a broad range of behaviors determining the interaction between the user, the product and the environment. The results of simulations can clearly be considered a kind of forecasts, therefore a valid question would be, if integrating all those simulations into an overall use-process simulation technique can be the most auspicious way to realize use-process forecasting. After all, there are obvious tendencies towards more integrated forms of simulation already, for instance multiphysics.

Yet, there are some typical, mutually related issues related to the diversity of use processes and the quantity of knowledge involved in such an overall use-process simulation, that tend to make its feasibility implausible. Simulations typically strive to deliver completeness in the output. Simulation applied to the totality of the use process would be aimed at delivering the complete course of one entire use process. Especially when it comes to forecasting compound processes like the use process, this focus on completeness becomes an obstacle. The intended completeness in the output strongly depends on completeness of input data. Use-process simulation would need a complete model of the U-P-E system, a complete specification of starting conditions and the course of all external influences. However, in conceptual design, but likely even in detail design it is not realistic to assume these are all available, therefore the feasibility of a 'complete' result is disputable. The value of such a result is also dubious, in two respects.

In the first place, the *predictive* value is limited. Due to the numerous nonlinearities in the various simulation modules, the slightest inaccuracy in input data can have considerable influence on the end result. The second reason is that the *practical* value of knowing the course of one specific use process is limited. For adequate anticipation of the use of a product, countless simulations for different users and different environments in different situations would be needed. A designer wants to know which courses of the use process are probable, and therefore have to be anticipated in the design, based on statistical data on the user population, possible environments, etc. Handling multiple possible courses (i.e. branching) and probabilities are not the typical strength of current simulation techniques. Also, there are no signs that developments in techniques for modeling humans are progressing towards support of modeling *populations* consisting of different individuals. In several relevant areas, such as cognitive-behavior modeling, the notion that every person is different has hardly been explored at all.

We have to conclude that, although actor models and simulations are capable of containing and providing valuable knowledge about the course of the use process, full-featured use-process forecasting cannot be based on these techniques alone.

5. Discussion

Neither process-modeling techniques nor actor-modeling techniques alone appear to offer sufficient potential for development towards a full-featured system for use-process modeling and forecasting. Yet, it appears to be interesting to explore how the strengths of both perspectives can be combined into a solution. Models of the user, the product and the environment incorporate the background knowledge about how and why interaction between the three actors U, P and E involved in a use process takes place. This knowledge is utilized in simulation. In simulation results, fragments of a process can already be recognized. Therefore, simulation can be considered to form a bridge between the actor point-of-view and the process point-of-view. However, current actor models and simulation techniques tend to focus on aspects, therefore, a single simulation can never offer a complete view of the use process. Here, process-modeling techniques can help to build up use-process forecasts, by combining and structuring simulation fragments. In the next paragraphs, we take a closer look at what can actually be integrated by straightforwardly combining the techniques, and how this can be implemented as a workflow in conceptual design. Subsequently, we make an inventory of what remains uncovered and what is still missing.

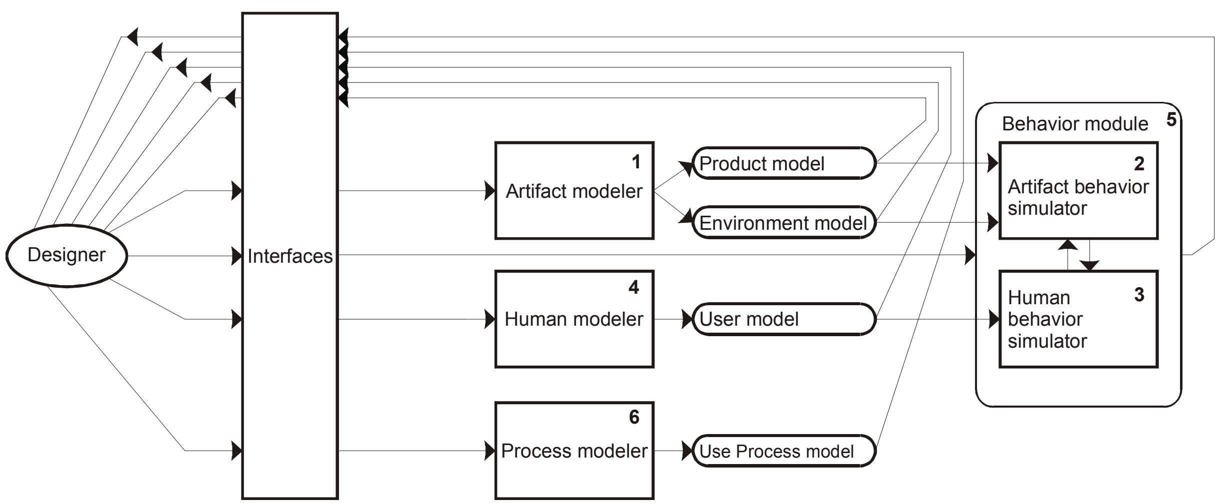


Fig. 7 A hypothetical system implementing use-process aspects in design support, based on the current state of the art and ongoing developments.

Fig. 7 shows a plausible setup for integration. In the depicted system, the designer can work with an artifact modeling system (1) not only to model the product but also the environment. As is shown in Section 4.1, simulation techniques (2) are advancing towards complete predictive coverage of the behavior of artifactual systems, in our case consisting of product and environment. To make the system fit for use-process forecasting, simulation should also include the user. For that purpose, the increasingly powerful human-behavior simulation tools (3) from the field of computer graphics (as discussed in section 4.2) can be used. User simulation will need input from human models as they are used in areas like computer graphics and anthropometrics, and which can be created with human-modeling systems (4). User simulation and artifact simulation will have to be combined into an integrated behavior module (5). The designer has to provide starting parameters for the simulations: positions, starting times, user intentions etc. A 'conventional' use-process model (or an improved combination of existing models) as discussed in section 3 could assist the designer in collecting the necessary parameters. The designer can create a use-process model with the help of process-modeling software (6) that is similar to the software commonly used to create process models for manufacturing systems and flowcharts. The use-process model can be further completed with results from the simulations, so that it will eventually represent some kind of use-process forecast.

The primary contribution of process modeling in this workflow would be to deal with the issues mentioned in subsection 4.3, i.e., the diversity of use processes and the quantity of knowledge involved in an overall use-process forecast. The completeness demanded by simulations can be resolved through a 'clever' decomposition of the use process into smaller parts or *simulation chunks*, which require a less massive amount of input data. This decomposition does not exclusively have to be a subdivision into fragments of time. It can also focus on particular types of behavior (mechanical, thermal etc.) or on specific areas where interaction takes place (for instance the user's hand and a button that is part of the product). At present, successful simulations in product-behavior prediction also tend to cover limited events, e.g. 'the lid of a coffee-pot product hitting the floor'. The diversity of use processes can also be handled through the various branching schemes offered by process-modeling techniques.

In order to make the realization of this system possible, several extensions of current R&D efforts are still needed. Existing actor models and simulation techniques do not yet completely cover the use process, although various parts of what would be needed are already available. Some need further development, adaptations or verification. The essentials appear to be (a) further integrated simulation of the different types of human behavior and (b) integrated simulation of artifacts and humans and (c) integration of process-modeling techniques. Nevertheless, even if these needs are fulfilled in the near future, the designers that will work with a setup as depicted in Fig. 7 will face limitations and impracticalities that can be summarized into three issues:

1. Designers will have to concern themselves with use-process modeling. This is likely to be considered an unrewarding job, since it only indirectly contributes to the eventual product. Some useful knowledge about use processes can possibly be retrieved from past experience in the company, but it is typically not in a form prepared for modeling. If use-process modeling is omitted from the setup, the use-process forecast will only consist of unconnected simulation results without cohesion and without a use-process context.
2. For accurate preservation of the course of use processes, use-process models should not only represent discrete states, but also the continuous transitions that result from simulations. Such models have not been fully developed yet. Moreover, current software applications for process modeling will not be able to support such models.
3. The designer still has to specify the input for simulations, in the form of starting times and other quantitative parameters. The use-process model that is intended to help him is still relatively superficial. It will not contain all the necessary quantitative parameters.

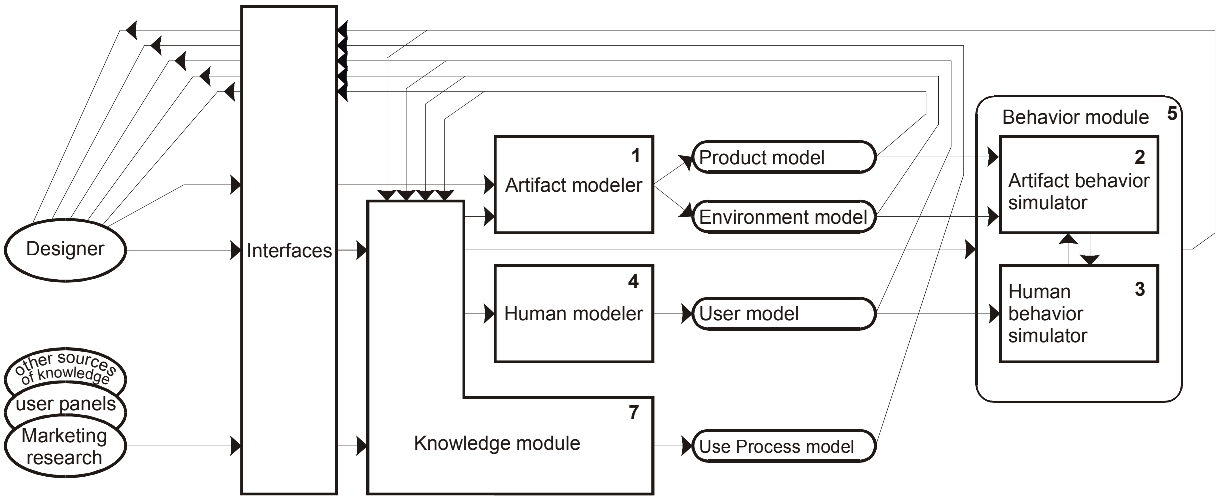


Fig. 8 Enhanced support of use-process forecasting through knowledge engineering.

These issues concern the content of use-process knowledge and the way it is represented. In the final section we will outline some possible solutions.

6. Conclusions

The current state of the art and the ongoing developments described in this survey appear to offer a good starting point for the inclusion of use-process forecasting in design support systems. For companies and researchers who intend to include use-process forecasting in design-support systems, a logical approach towards a full-featured system appears to be to combine modeling techniques for actors in the use process with process-modeling techniques. Such a combination benefits from (a) the knowledge-containing power in the actor models and (b) the representation and structuring power that is offered by process-modeling techniques. When it comes to the knowledge content of the use process, the main issue appears to be how to handle and to represent the knowledge that is supposed to flow through the various modules of the system. At a more concrete level, the main issues are

- The knowledge that exists in the company and in the designer's head cannot be digested by conventional process-modeling systems and cannot be represented in conventional process models;
- The knowledge represented in conventional process models cannot be used to define starting parameters for simulations;
- The knowledge represented in the output of simulations cannot be used in conventional process models.

The field of science that typically deals with this kind of problems is *knowledge engineering* (KE). The authors believe that KE techniques can help to resolve the knowledge mismatches that complicate use-process forecasting in computer-aided conceptual design. Fig. 8 shows how the system depicted in Fig. 7 can be extended with a *knowledge module* (7) to process all different kinds of use-process knowledge in order to build up and maintain a use-process model. The knowledge module manages a use-process model that fits three needs:

- The UPM can be built up with use-process knowledge from past projects in the company. If needed, it can be completed with designer input. Additionally, the knowledge module might be equipped to accept use-process knowledge from other sources, e.g. from marketing research or from user-panel trials, as indicated in Fig. 8.

- It contains knowledge that can be converted into input parameters for simulations;
- It is capable of preserving the continuous transitions that result from simulations, rather than preserving just discrete states and actions.

Beside building up and maintaining the UPM, the primary tasks of the knowledge module are:

- maintaining a knowledge base with company knowledge concerning use processes;
- converting knowledge in the UPM into simulation parameters, and
- preparing simulation results to be incorporated in the UPM, and also in the knowledge base for future availability.

Gradually, as the system is used in more projects, UPMs will contribute to the company's use-knowledge base, providing quantitative input that can be used for simulations directly in the beginning of new projects. The use-knowledge module can play a prolific role in organizing the simulation chunks into the UPM. Simulation chunks can also be stored in the knowledge base for future use in other projects. This is expected to reduce the need for process-modeling input from the designer. The use-knowledge base does not have to be restricted to process knowledge. The company's use-knowledge base is likely to contain valuable use-related knowledge about known user populations, known use environments and previous products. By handling this knowledge as well, the knowledge module can facilitate the designer's dealings with environment modeling and human modeling. For instance, the knowledge module might be able to initiate simulations with sample users from the intended user population. Knowledge about previous products can be made available in the same form as current usability guidelines, i.e. as recommended artifact characteristics that ensure usability of a given type of product. The advantage over conventional usability guidelines will be, that the artifact knowledge will not be disconnected from the use-process knowledge, so that the reasons behind the guidelines will be more transparent to designers.

The ideas outlined in the above paragraphs are only a first draft of what might be possible. Considering the complexity of the various issues, it is clear that full-featured use-process forecasting and modeling is not an achievement that can be expected on the short or medium term. This is even more true because there is no currently ongoing research towards use-process modeling. Our research project, in which we will further investigate the knowledge issues discussed in this section, can be a starting point. Hopefully, the forthcoming results of this research will inspire initiatives in other fields like computer graphics, human-behavior simulation etc., since it is obvious that developing support for use-process modeling and forecasting has to be a truly multidisciplinary effort.

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