# A Tentative Design Model for Smart Products

Wolfgang Maass

Hochschule Furtwangen University
Robert-Gerwig-Platz 1
78120 Furtwangen, Germany
wolfgang.maass@hs-furtwangen.de

March 30, 2007

**Abstract**

Smart products are hybrids of physical products and information products that leverage cheap and wireless information and communication technologies. Currently different kinds of smart products are proposed and tested under various umbrellas, such as Ubiquitous Computing and Ambient Intelligence. With increasing maturity of these technologies, it will be required to better understand design methods for smart products that can be rigorously applied and used for system evaluation. In this article, we outline a tentative design model for smart products that integrates various design levels into an homogeneous model. This design model is discussed on the basis of three systems that qualify as smart products. As a result it will become clear that the systems only partially use rigorous design models but are more based on implicit design principles which opens up a new field of research.

## 1 Introduction

Ubiquitous Computing, Pervasive Computing and Ambient Intelligence are strongly growing research fields that generate an enormous amount of prototypical systems [BD07]. Similar to other fast growing technology-driven research fields, also these fields will have to prove that they are able to translate this research energy into viable, robust and wealth improving products and services. A vast amount of research prototypes are developed that express feasibility of integrating information technology into physical environments and networking of devices, new aesthetic design principles, and sometimes search for new product types, markets and economic advantages. It is rudimentally visible that resulting products and services will integrate physical and information worlds in unprecedented ways which are summarised in the following by the term *smart product* [MF06]. Smart products are specializations of hybrid products with physical realizations of product categories and digital product descriptions that provide the following characteristics [MF06]:

- Situated: recognition of situational and community contexts,
- Personalized: tailoring to buyer's and consumer's needs and affects,
- Adaptive: change according to buyer's and consumer's responses and tasks
- Pro-active: attempt to anticipate buyer's and consumer's plans and intentions,
- Business-aware: consideration of business and legal constraints, and

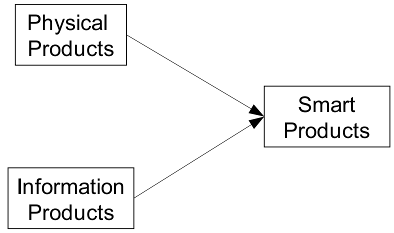


Figure 1: Merging physical products and information products into smart products

- Network capable: ability to communicate and bundle with other products

Ubiquitous computing technologies aim at embedding information technologies into physical environments, i.e. bringing information and interactions to the user while hiding technologies [Wei02]. In this sense, smart products are hybrids of physical products and information products. While the design of physical products is well-grounded in areas, such as engineering and marketing, design of information products is a very young field [SV99] and has been mainly covered by interface design research [Shn97]. From this perspective, we propose a holistic design model that helps to adjust the physical side of a smart product with the information side and vice versa (cf. fig. 1).

In the following we first present the literature within the domain of traditional product design of physical products and information products (section 2) before we discuss a collection of different design aspects that will be integrated by a tentative design model (section 3). In section 4, we apply this design model to three different application cases and finish with a summary and a brief outlook (section 5).

# 2 Design as Part of New Product Development

Design research defines the term product as follows: "*products are artefacts conceived, produced, transacted and used by people because of their properties and functions they may perform*" [RE95]. By a more recent definition "*a product concept is a description of a product in accordance with attributes perceived by the target customers*" [NMAG04]. Both are representatives of a functional design perspective which focuses on the utility of products. But as indicated by the Apple iPod, product designs are also governed by emotions, aesthetics, haptic, and other sensual experiences.

Furthermore products help individuals and groups to express social relationships. For instance, driving a particular car type or wearing a particular jeans can express an affiliation with a particular social group. Hence, products are not only involved in human-product-interactions but can be part of social interactions. Products can be either perceived as tools or sometimes as role-taking entities themselves. The more a product seems to use human-like communication skills the more it is accepted as a role-taking entity. Examples are Aibo, KITT in the TV series "'Night Rider"', or HAL in "'2001: A Space Odyssey"'.

Over the years, vendors of physical products have learned to perceive a new product development (NPD) process as a management task that can be planned, structured and controlled [ZM90, HSC98]. Step by step, design has become a central element of NPD processes as a means to create innovative, creative customer need oriented products [PCC05]. Nonetheless the role of design is underspecified, which means that the specific tasks of a designer are still unclear [PCC05]. It is argued that designers should embrace traditional marketing tasks [VS03] and should directly interface with the marketplace to effectively understand the customer [LR97]. *Product* *design* as a process can be perceived as "'*the process of devising and laying down the plans that are needed for the manufacturing of a product*"' [RE95].

A design model for products must conceive the tool aspects as well as the role-taking aspects. Generally, designs of products are (1) descriptions of externally perceivable behavior of a smart product and (2) models of situations in which a smart product can be used. Most design methods for New Product Development focus on the first aspect [UE95, PCC05].

We start from the hypothesis that designing a smart product according to anticipated situations is a key element of an integrated design model for smart products. A situation can be given by interactions of a single user with a single smart product, interactions of a group of users with a collection of smart products or permutations of these situations.

Next, we will briefly introduce the state of the art of designing physical products and information products before we merge this into an integrated design model for smart products.

## 2.1 Product design of physical products

For physical products, product development is a critical management issue in particular for technology driven industries [ZM90]. Development cycles are continuously decreasing while the quantity of innovations increase [Ham82].

Ulrich and Eppinger, for instance, distinguish the process of product design of physical products into five phases [UE95]: (1) concept development, (2) system-level design, (3) detail design, (4) testing and refinement, (5) production and ramp-up. In recent years, a stronger customer-oriented perspective has been adopted [PCC05, SH98]: (1) identification of the need, (2) concept development, (3) design, (4) production, (5) launch. A huge amount of qualitative [GP02] and quantitative tools [Hsi02] have been developed for the new product development processes.

## 2.2 Product design of information products

Information products have different characteristics than physical products, e.g., negligible marginal costs of re-production, experience good qualities, i.e. evaluation of product qualities after buying decision making, copy dilemma, i.e. a copy and original are undistinguishable [SV99]. Because information products are rather new product types it is not surprising that design methodologies for information products rarely exist. For the content side designers of information products take advantage from principles of journalism, such as news principles: accuracy, brevity and clarity. But interactive information products, such as web sites, are not only content but media with more complex design requirements. For the design of complex information products, Armitage distinguishes six feature types [Arm03]: (1) metaphor, (2) mental models, (3) navigation, (4) interaction, (5)information, and (6) functionality and the following fields of expertise:

- appearance design: determines the surface form,
- information architecture: organization and taxonomy of information networks,
- interaction design: product use and behavior,
- user interface design: the part the user perceives and must deal with,
- digital product design: conceives, prototypes, and specifies a complete working product that features digital technology, and

- experience design: All products used by people are experienced, and the experience of using a product is dominated by it design.

Often the role of a designer for information products is described as conceptualization and implementation of user interfaces (e.g., [Arm03, Mar02]).

In summary, design methods for physical products are mainly driven by procedural and functional viewpoints while design methods for information products are collections of loosely coupled viewpoints and principles which renders them as being widely incompatible with one another. Therefore we will describe in the following an integrated tentative design model that can be applied on the design of smart products.

# 3 Design model

Deploying smart products in an application environment means to place them in usage situations with other products, services and users. A user uses a product, and in particular smart products, based on his understanding of the product interface, anticipation of application results, perception of the product appearance and associated emotions, its acceptance by other users, his rights, its compatibility with other products and services, its internal structure, and tasks to operate this product in the long run. In practice, a user only picks some aspects explicitly and covers other issues by default knowledge while a product designer considers all aspects to achieve a best fitting product.

We dissect logical design aspects into *primary designs* that cover key design issues and *secondary designs* that support the overall design of a product. Primary designs perceive a product as a communicative part of a social system that interacts with social actors, products and services, and has a particular appearance. The secondary design addresses aspects how to operate a product and its architecture and how it is implemented by using particular infrastructures.

Primary designs are dissected into four logically distinct designs while secondary designs encompass three designs:

1. Primary designs
   (a) information design: static and dynamic information that is processed by a product
   (b) form & physics design: appearance of a product and materials that are used to build it
   (c) organization design: social systems in which a product can be used
   (d) services design: functional interface of a product and collection of services that are compatible or required
2. Secondary designs
   (a) architecture design: internal static and dynamic structure that represents the external behavior of a product
   (b) infrastructure design: the matter that implements primary designs, architecture and management designs
   (c) management design: economic and managerial issues that are required to operate a product and production environments

All design levels will be discussed in the following.

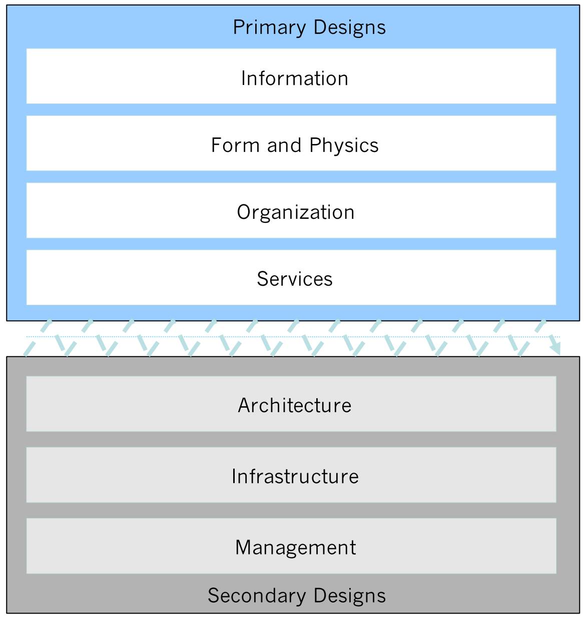


Figure 2: Generic design model

### 3.1 Information design

A product can be used if it offers some kind of an interface to a user or other products. This interface is a communication channel that exchanges information based on defined languages. These languages range from static labels (e.g., stickers on cereal packages), simple interactive languages (e.g., control boards of washing machines), language collections (e.g., multimedia-navigation control in cars) to complex multimodal languages (e.g., SmartKom [Wah03]). Such product languages generally tap into existing languages or metaphor systems known by particular communities, e.g., automotives, Sony Walkman, email or digital paper [HVA+05]. This approach reduces learning efforts and increases the acceptance of new technologies [Fis04]. New language will have to be learned by actors before usage, e.g., Smart-Its [GKSB04] or cube interfaces [SSK+03].

Product language are designed on all three levels of natural languages: (1) syntax, (2) semantics, and (3) pragmatics. The syntax, and in particular its grammar, defines the rules that define the correct construction of expressions in a language. The meaning of symbols, words and phrases is defined by its semantics. The semantics of a word in product languages is generally not defined by closed formal statements but are rooted in more basic understandings about a particular domain. For instance, the symbol of a boiling pot refers to a situation where water exceeds 100 degree Celsius but also user experiences with boiling water, such as burning one's fingers.

The information view is not restricted to textual or graphical symbols but encompasses also other senses. Porsche, for instance, is well-known for designing its "sound language" or digital cameras simulate the shutter click by sound chips.

The pragmatic aspect of a product language is rarely considered because it is assumed that products express simple information. But, as soon as products become more communicative it will become tedious if complex issues are always described in a simple, propositional language. Communication with smart products might take advantage of richer speech acts, most of all illocutionary speech acts, that transport implicit intentions. This will lead to more natural communication as already envisioned by science fiction novels.

If products are involved in complex communication situations they are required to maintain the discourse of a communication, understand the roles and intentions of participants in a communication and adjust its communication behavior according to its own intentions and plans. For instance, an ambient tourist guide system for groups must balance the information needs of all participants but must also stick with a predefined time frame.

## 3.2 Form&physics design

Tangible products exhibit important key attributes that are either physical, e.g., weight, temperature, surface structure, or form dependent, e.g., round, squared, sharp, thick. Both are context dependent. For instance, a telephone might have the right form and material for business meetings but might be perceived as being clumsy and pretentious when used at a pool. The form and the physics of a product communicate the emotional status of a user and his general attitude. For instance, the form of an iPod is perceived as standing out which differentiates its user. Form might even negatively interfere with other design aspects [Nor02].

Form and physics of a product are the domain of engineering, material sciences, psychology, and marketing. Nonetheless a homogeneous product design requires an integration with other design views so that negative interferences are avoided.

## 3.3 Organization design

The information view already indicated that products are generally deployed in social environments with actors, entities, stages, backgrounds and foregrounds. Actors can take different roles, e.g., buyer, seller, product, content supplier. The basic organization view describes the roles that prototypically interact with a product (e.g., [Sch02]). The static organization describes rights and functions ascribed to a role while the dynamic part describes the interactions in time. Beside structural elements, the organizational view also includes cultural and emotional aspects related to a product. For instance, the interpretation of colors is culture-dependent and induces different feelings. This happens also in smaller social groups. For instance, the acceptance of a particular gaming system might depend on the user's peer group.

Two design scenarios can be distinguished: (1) products are designed as tools that can be used by role-taking individuals on organizational level or (2) products are designed as role-taking entities itself. In the second case, products become actors on organizational level and can directly interact with other roles [SM97]. Philips iCAT and Sony's Aibo are examples for role-taking products. Products can approximate full implementation of role concepts if they encompass agent capabilities [KM96, AGA06], for instance, based on the BDI-model [RG95].

The dynamic structure of a product is described by protocols or process descriptions. Most parts of user manuals are dedicated to an explanation of dynamic product behavior. The interaction design of a product describes: (1) *interaction types* (protocol and processes) in which a product is used on abstract level, i.e., business processes, eduction processes, web service protocols etc., (2) *specification of interactions on physical level*, i.e. a description how other roles and services can interact with a smart product on physical level such as handling on/off switches, and (3) *specification of interaction on informational level*, i.e. a description how role-taking actors and services can interact with provided information. Examples are communication, navigation structures, selection of information presentations and content types.

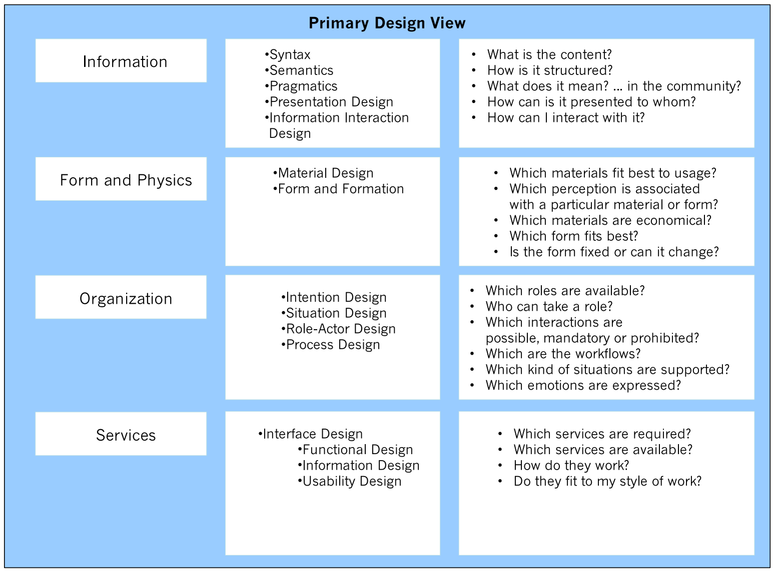


Figure 3: Primary design view

## 3.4 Service design

Services provide interfaces that define how they can be used by role-taking actors or by other services. Different actuation of services are used, e.g., touch-based services, natural language services and gesture recognition services. A large number of smart products provide services to role-taking individuals, e.g. [GKSB04, SSK+03]. In this case, service interfaces are specified on interaction level and implemented by this particular class of smart products. Existing description formats for service-to-service interactions, such as WSDL [CCMW01], can be used as starting points for formal service interface descriptions. For non-standardized service interactions, service interface semantics can be formalized by service (e.g., OWL-S [GPGCL04]) and task representations (e.g., DDPO [GBCL04]).

Service interfaces are abstractions of services. Implementations are required to comply with service interface definitions that in turn comply with the product language used in the associated information design and organization design. If the implementation differs from anticipated product languages this might lead to inadequate usage behavior. Hence, service interface descriptions are key elements for grounding of product languages, i.e., with the help of product interfaces actors associate meaning with symbols and behavior of services. This knowledge can be generalized and used as prototypical information for the interpretation of other products.

The primary design view is summarized in fig 3 together with a list of exemplifying questions.

## 3.5 Architecture design

The internal structure of a product is described by its architecture. The architecture is the scheme by which static and dynamic elements defined by organization designs are implemented by detailed logical entities and relationships. For physical products these entities are mainly physical while for information products these entities are mainly defined by algorithms and software elements. The information design is generally a minor part of physical product designs which mainly focuses on the translation of system-level designs, i.e. designs of the organization and form&physics, onto system engineering level by applying modular, integral and/or platform strategies supported by CAD systems [ML97].

For smart products we require integrated architecture design methods that allow consistently the translation of designs of primary views into architectures.

### 3.6 Infrastructure design

The architecture of a product is still a logical construct. Together with primary designs, the architecture is implemented by appropriate infrastructures. Physical products are implemented by physical materials while information products are implemented by digital matters. In smart products information products are embedded into physical products which requires integrated implementation methods. More abstract, primary designs, architecture designs and management designs define a complex interrelated constraint network which restricts the set of possible implementations.

### 3.7 Management design

The final secondary design is given by the management design which aligns all other designs with producer's capabilities, economic constraints and management objectives. Products are packaged performances that capture a provider's knowledge in such a way that it can be leveraged by customers. A management design encompasses an economic design and an operational design of a product. The economic design copes with the economic viability of a product, most of all whether sufficient supply and demand ratios can be achieved for a particular price differentiation [Dil00] and profit strategy over time [MR92].

The operational design describes the operationalization of an economic design. Key issues are allocation of resources, team management, supply chain and infrastructure management, and communications.

## 4 Application of the design model on sample systems

The application of the proposed design model will be discussed in the following by *Engine-Info* [MM05] as an example for a service-oriented smart product, *iCAT* [vBYM05] and *Leonardo* [Bre04] as examples for role-taking smart products.

Engine-Info provides a wearable interface for attentive-sensitive interaction with physical objects and is part of MIT's Invisible Media project. The iCat project investigates animated robotics on the basis of a generic software platform, OPPR, and is part of Philips "smart home research". iCat is a front end for robotics that operates autonomously and aims at appearing believable to users. Similarly, Leonardo is a socially and emotionally autonomous robot that interacts with people. It is part of the Robotic Life group at the MIT.

### 4.1 Information design

As summarized in table 1, all systems lack a consistent information design that encompasses syntax, semantics and pragmatics. Engine-Info's communication is based on pre-configured content that lacks a representation of its semantics. iCat executes scripts with predefined phrases. Leonardo focuses on the analysis of user input and on presentation of emotional information. The context is represented by "antecedent conditions" that define patterns of emotional status and related

| Design views | Smart Service | Smart Product | Smart Product |
|---|---|---|---|
| Examples | Engine-Info | iCat | Leonardo |
| *Primary designs* | | | |
| information | (•) | input & emotions | (•) |
| form&physics | (•) | • | • |
| organization | | | |
| *functions* | • | • | • |
| *situations* | – | • | (•) |
| *role-actor* | – | (•) | (•) |
| *intentions* | – | (•) | (•) |
| services | none | none | none |
| *Secondary designs* | | | |
| architecture | functional, closed | behavioral, closed | behavioral, open |
| infrastructure | electronics, wireless communication, software | robotics, software | robotics, software |
| management | undefined | undefined | undefined |

Table 1: Evaluation of examples of smart product against the design model

behavior. Emotional status and deduced behavior are used for subsequent activation of appropriate functions, e.g. "explore environment".

## 4.2 Form&physics design

The form&physics design of Engine-Info is rather simple while iCat and Leonardo emphasize the role of a pleasant form. None of the systems has applied a method for designing form&physics of the system, such as [RK07].

## 4.3 Organisation design

The organisation design focuses on interactions between systems and users that are based on basic and commonly accepted usage pattern. All three assume simple dialogue schemes between a single user and the system while iCat allows role-switching during a dialogue. None of the systems is able to process roles - neither the role of the system in a situation nor the role of single users or user groups. Intentions are only anticipated by Leonardo on emotional level. But the question is how robust emotional patterns are. For instance, prolonged absence of a desired stimulus is interpreted as sorrow. This might be wrong if the user was interrupted by a telephone call. In summary, the organization design is rather rudimentary in all three cases.

## 4.4 Service design

The focus of all three system lies on the service design. The function set is reduced which indicates that the design aims at simple and controllable functionalities. This is probably the reason why situations on organisation level are neglected by Engine-Info and iCat. As mentioned, Leonardo captures the current situation by emotion pattern while information about sequences of emotion patterns are not evaluated.

The functional design is based on commonly accepted, basic communication behavior patterns.

### 4.5 Secondary designs

Only iCat's architecture is designed as an open system that is able to integrate external services on technical level. None of the systems is designed to use services on functional level. The architectures of iCat and Leonardo are designed to exhibit human-like behavior. The basic architectural design principle of iCat and Leonardo follow an outside-in strategy, i.e., functions drive implementation, while Engine-Info is driven by an inside-out strategy.

All three systems are implemented by electronic infrastructures. iCat and Leonardo are also implement on electro-mechanical systems used in robotics. Engine-Info uses wireless communication technologies (bluetooth) for connecting headsets with a central server. Management issues are generally not considered.

### 4.6 Summary

This brief discussion might show that design methods have not been used in all three examples which, in turn, indicates that system feasibility is the focus of research. Only Leonardo uses a structured approach for mapping user behavior with system behavior that might allow evaluation of system behavior against designs of different logical levels.

## 5 Summary and open issues

Rigorous design methods are important tools for the development of high-quality products. We have presented a tentative design model that integrates the physical and the information side of smart products. Primary designs embrace four different logically distinct designs that allow a modular perspective on products. Information design copes with information that is exchanged between products and its environments. Research in physical product design indicate that differentiation on physical level is very small and provides almost no competitive advantage which leads to an increasing importance of information design of smart products in the future.

Designing form&physics is the domain of industrial design that must be integrated with other design levels. Otherwise products with excellent forms might be doomed to stay useless because its information or functional design cannot be understood by users.

The examples showed that the organizational design of smart products is in its infancies. Role-actor designs, intentional designs and situation designs are currently neglected. Only Leonardo showed an interesting attempt to process contextual information of a situation. Service designs define service interfaces that can be used on behavioral, i.e., human-product-interactions, or technical level, i.e. product-product interactions. On behavioral level service designs will have to provide clear languages that can be easily understood by users. It might be helpful to distinguish between static and dynamic parts of service interfaces.

Secondary designs encompass architectural, infrastructure and management designs. While the first two designs are part of engineering in general, the latter is rarely an integral part of product design methods. Finally an integrated design model for smart products requires a management design that is developed in parallel with primary and other secondary designs.

Our future work aims at a better understanding of designing smart products with a focus on supporting methods. We will elaborate each design with a specific focus on evaluating different design methods from electronic and mechanical engineering, industrial design, and software engineering. The second step is to extend this approach to behavioral sciences, such as sociology for organization designs, psychology for information designs, economics and management theory for management designs.

A thoroughly crafted design model shall be used as a means for developing robust smart products in a more rigorous way than today but also to use it as a framework for proper evaluation of smart products.

## References


[AGA06] M. Armentano, D. Godoy, and A. Amandi. Personal assistants: Direct manipulation vs. mixed initiative interfaces. *Journal of Human-Computer Studies*, 64:27–35, 2006.

[Arm03] J. Armitage. From user interface to ber-interface: a design discipline model for digital products. *interactions*, 10(3):18–29, 2003.

[BD07] G. Bell and P. Dourish. Yesterday's tomorrows: notes on ubiquitous computing's dominant vision. *Personal Ubiquitous Computing*, 11(2):133–143, 2007.

[Bre04] C. Breazeal. Function meets style: insights from emotion theory applied to hri. *Systems, Man and Cybernetics, Part C: Applications and Reviews, IEEE Transactions on*, 34(2):187– 194, 2004.

[CCMW01] E. Christensen, D. Curbera, G. Meredith, and S. Weerawarana. Web services description language (wsdl) 1.1. Technical Report W3C Note 15 March 2001

[Dil00] H. Diller. *Preispolitik*. Kohlhammer, Stuttgart, 3rd. edition, 2000.

[Fis04] K. A. Fishkin. Taxonomy for and analysis of tangible interfaces. *Personal and Ubiquitous Computing*, 8(5):347–358, 2004.

[GBCL04] A. Gangemi, S. Borgo, C. Catenacci, and J. Lehmann. Task taxonomies for knowledge content. Technical Report D07

[GKSB04] H. Gellersen, G. Kortuem, A. Schmidt, and M. Beigl. Physical prototyping with smart-its. *Pervasive Computing*, 3(3):12–18, 2004.

[GP02] F. Gonzalez and T. Palacios. The effect of new product development techniques on new product success in spanish firms. *Industrial Marketing Management*, 31:261–271, 2002.

[GPGCL04] A. Gomez-Perez, R. Gonzalez-Cabero, and M. Lama. A framework for description, composition, and evaluation of semantic web services. *Intelligent Systems*, Special Issue on Semantic Web Services, 2004.

[Ham82] Booz Allen & Hamilton. *New Products Management for the 1980s*. Booz Allen & Hamilton, New York, 1982.

[HSC98] M. Hill, A. Schilling, and W. L. Charles. Managing the new product development process: Strategic imperatives. *The Academy of Management Executive*, 12(3):67–81, 1998.

[Hsi02] S. W. Hsiao. Concurrent design method for developing a new product. *Industrial Ergonomics*, 29:41–55, 2002.

[HVA+05] D. Holman, R. Vertegaal, M. Altosaar, N. Troje, and D. Johns. Paperwindows: Interaction techniques for digital paper. In *Proc. of Computer Human Interaction (CHI) 2005*, pages 591–599, 2005.

[KM96] T. Koda and P. Maes. Agents with faces: The effects of personification of agents. In *Proceedings of Human–Computer Interaction (HCI)*, pages 239–245, 1996.

[LR97] D. Leonard and J. Rayport. Spark innovation through emphatic design. *Harvard Business Review*, 75(6):102–114, 1997.

[Mar02] A. Marcus. Fast forward: Dare we define user-interface design? *interactions*, 9(5):19–24, 2002.

[MF06] W. Maass and A. Filler. Towards an infrastructure for semantically annotated physical products. In Ch Hochberger and R. Liskowsky, editors, *Informatik 2006*, volume P-94 of *Lecture Notes in Informatics*, pages 544–549, Berlin, 2006. Springer.

[ML97] M. Meyer and A. Lehnerd. *The Power of Product Platforms*. The Free Press, 1997.

[MM05] D. Merrill and P. Maes. Invisible media: Attention-sensitive informational augmentation for physical objects. In *Seventh International Conference on Ubiquitous Computing (UbiComp'05)*, Tokyo, 2005.

[MR92] P. R. Milgrom and J. Roberts. *Economics, Organization and Management*. Prentice-Hall, Englewood Cliffs, 1992.

[NMAG04] M. Natter, A. Mild, Taudes A., and C. Geberth. Web-based knowledge management in product concept development - the deli approach. *International Journal of Electronic Business*, 2(5):471–479, 2004.

[Nor02] D. A. Norman. *The Design of Everyday Things*. Basic Books, 2002.

[PCC05] H. Perks, R. Cooper, and Jones C. Characterizing the role of design in new product development: An empirically derived taxonomy. *Journal of Product Innovation Management*, 22:111–127, 2005.

[RE95] N. F. M. Roozenburg and J. Eekels, editors. *Product Design: Fundamentals and Methods*. Wiley & Sons, Chichester, UK, 1995.

[RG95] A. S. Rao and M. P. Georgeff. BDI agents: From theory to practice. In *First International Conference on Multiagent Systems*, pages 312–319, 1995.

[RK07] Ph. Ross and D. Keyson. The case of sculpting atmospheres: towards design principles for expressive tangible interaction in control of ambient systems. *Personal Ubiquitous Computing*, 11(2):69–79, 2007.

[Sch02] B. Schmid. Inszenierung von produkten im e-business. In W. Wunderlich and S. Spoun, editors, *Medienkultur im digitalen Wandel*, pages 91–113. Haupt, Bern, 2002.

[SH98] M. Schilling and Ch. Hill. Managing the new product development process: Strategic imperatives. *Academy of Management Executive*, 12(3):67–82, 1998.

[Shn97] B. Shneiderman. *Designing the User Interface*. Addison-Wesley, Reading, MA, 1997.

[SM97] B. Shneiderman and P. Maes. Direct manipulation vs. interface agents. *Interactions*, 4(6), 1997.

[SSK+03] J. G. Sheridan, B. W. Short, G. Kortuem, K. Van Laerhoven, and N. Villar. Exploring cube affordance: Towards a classification of non-verbal dynamics of physical interfaces for wearable computing. In *Proc. of the IEE Eurowearable 2003*, pages 113–118. IEE Press. Birmingham, UK, 2003.

[SV99] C. Shapiro and H. R. Varian. *Information rules - A Strategic Guide to the Network Economy.* Harvard Business School Press, 1999.

[UE95] K. Ulrich and S. Eppinger. *Product Design and Development.* McGraw-Hill, New York, 1995.

[vBYM05] A. van Breemen, X. Yan, and B. Meerbeek. icat: an animated user-interface robot with personality. In *AAMAS '05: Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems*, pages 143–144, The Netherlands, 2005. ACM Press.

[VS03] B. Von Stamm. *Managing Innovation, Design and Creativity.* Wiley & Sons, Chichester, UK, 2003.

[Wah03] W. Wahlster. Smartkom: Symmetric multimodality in an adaptive and reusable dialogue shell. In R. Krahl and D. Gnther, editors, *Human Computer Interaction Status Conference*, Berlin, 2003. DLR.

[Wei02] M. Weiser. The computer for the 21st century. *Pervasive Computing, first published: Scientific Amercian, 1991*, 1(1):18–25, 2002.

[ZM90] B. J. Zirger and M. A. Maidique. A model of new product development: an empirical test. *Management Science*, 36(7):867–883, 1990.