ON THE INTERACTION BETWEEN THE ENGINEERING DESIGN AND THE DEVELOPMENT PROCESS MODELS — PART II: SHORTCOMINGS AND LIMITATIONS

Damien Motte[1,a], **Robert Bjärnemo**[1,b] **and Bernard Yannou**[1,2]

[1] *Division of Machine Design LTH, Lund University, P.O. Box 118, 22100 Lund, Sweden.*
Email: [a]*damien.motte@mkon.lth.se,* [b]*robert.bjarnemo@mkon.lth.se*
[2] *Laboratoire Génie Industriel, École Centrale Paris, Grande Voie des Vignes, 92290 Châtenay-Malabry, France.*
Email: bernard.yannou@ecp.fr

Models of the engineering design process and of the development process nowadays present similar forms in the engineering design literature and interact in a similar way. These models are often presented as generic, in order to be used in a wide area of applications. This interaction is however not unproblematic, and in this publication we present some important issues and challenge the generic aspect of these models. In order to increase clarity, we have divided the publication into two parts. In Part I, the generally accepted engineering design and development process models are presented. The fundaments of the development model and the motivations behind its current form are highlighted. In Part II, the consequences in the form of severe shortcomings resulting from the interaction of the engineering design and development process models are highlighted. These shortcomings do not disappear when the systematic design process model is applied with alternative development process models. The implications for the further development of methodologies supporting design and development models are discussed.

Keywords: Engineering design process model, Development process model.

1. INTRODUCTION

In Part I [1] of this publication, the generally accepted engineering design and development process models have been presented and elaborated upon. In this Part, the shortcomings resulting from the interaction between these engineering design and product development process models are presented and discussed. Furthermore, the generic aspects of the current development model — the "funnel development model", see Part I, upon which the described interactions have been based are questioned. Alternative development strategies are presented. It is shown that the integration of the systematic design process model with those alternatives is also problematic. The arguments put forward in the two next sections, and their implications for further methodological development, are then discussed.

2. CHALLENGES OF THE INTEGRATION OF THE ENGINEERING DESIGN PROCESS IN THE FUNNEL DEVELOPMENT MODEL

The first observation that can be made is that the development of a product never starts in a vacuum. The company has as its disposal existing technologies (i.e. in the form of established working principles,

Research into Design — Supporting Sustainable Product Development. *Edited by* Amaresh Chakrabarti
 :: *Published by* Research Publishing
ISBN: 978-981-08-7721-7

components…etc) and develops new ones that it wants to use and re-use according to its overall development strategy. Consequently, many functions and working principles are fixed, the clients are relatively well defined and there is little room for questioning these imposed inputs once a project is launched. Moreover, the company has certain core competencies that it wants to exploit; searching for physical effects that would require other competencies is an activity that is unlikely to happen once the development has begun. Firstly it would require an initial access to broad competencies and subsequently acquiring these new competencies, either by education and training of existing staff or by hiring an expert in the field. This requires time and money, and is not free of risks. Secondly, it would very possibly have an impact on the company's development strategy, which would work against one of the reasons for the project planning activity: to relieve the project actors of any top level decision making. All in all, *this seriously reduces the need for a systematic development and evaluation of function structures, as well as systematic search and evaluation for new physical effects and working principles during the product development project: most of them are determined during product planning.* Moreover, any original technical idea — of a function, a working principle, or an embodiment — needs to pass some screening criteria at the product planning phase (e.g. compatibility with other functions, importance of the idea considering technological aspects, cost determination) and are thus likely to be investigated prior to project launch. So the product-to-be is quite advanced conceptually when the actual development begins.

When critical functions or working principles are being determined or imposed during product planning, it is still necessary to design the auxiliary ones. However, in that case, it is routine design, and there is less need for a systematic design approach (note that therefore the conceptual development of auxiliary functions is most frequently part of the embodiment design phase in [2]).

Systematic search to encompass the broadest range of solutions is also not a fundamental of the design activity during development.

In fact, the *new product development literature*, e.g. [3, 4], puts the conceptual development during the planning phase, while the engineering design literature, e.g. [2, 5] puts it during product development. Figure 1 shows the correspondences between the different models.

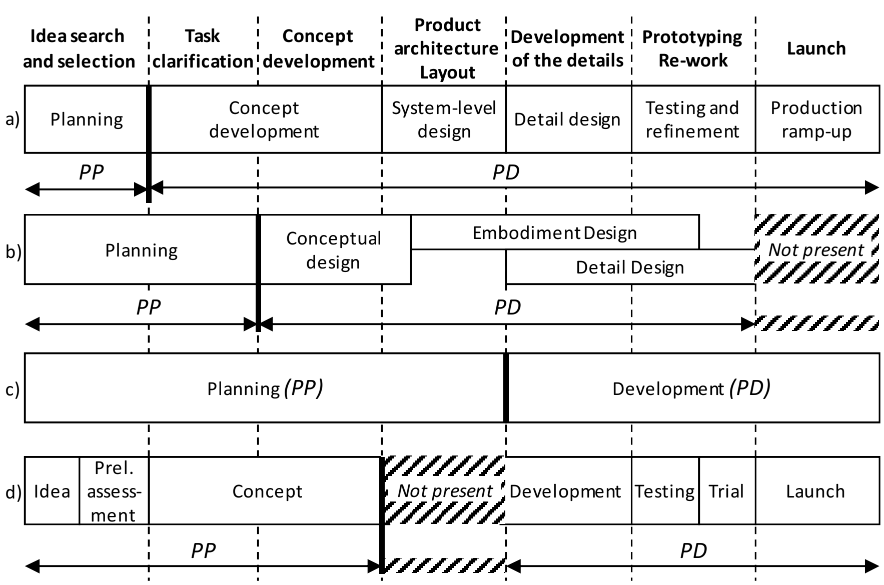

Figure 1. Comparison of planning and design process models from the engineering design literature and management literature: a) Ulrich and Eppinger [5], b) Pahl and Beitz [2], c) Wheelwright and Clark [3], d) Cooper [4, 9]. Note that in the figure, PP is short for Product Planning and PD for Product Development.

Concept development in all of the models has the same position relative to the other planning and development activities, so one could conjecture that putting concept development during planning or during product development is an arbitrary choice. But it is not clear-cut. The planning phase does not start from scratch either: the company has resources, skills, and capability that it wants to re-use. If new working principles (technologies) are interesting, they ought to go through a screening process that includes assessing their economical and strategic relevance to the company, while the methods for conceptual design concern mainly searching for solutions concerning consumer needs. The ideas come from multiple sources and in a continuous manner, as illustrated by Figure 2 in Part I [1], not necessarily at one point in a conceptual phase within a particular product development project, as suggested by the generic engineering design and product development process models. Importantly, new product ideas are defined in reference to existing versions or to competitors. This means that they are defined in term of differentiation and of the added value provided when new service or technical functions are added (see also [6]). *The broad search for an optimal product is not a priority in the product planning phase*.

Thus, 1) the search for new functions and working principles is made in relation to existing ones with the objective of being better and technically feasible, not optimal; 2) the search will rarely concern all the functions of an existing product, only the critical ones, and the combination of working principles becomes an auxiliary problem. This is reflected in the way design is conceived in the new product development literature. Design in development is seen merely as parametric design (in a loose sense): customers attributes are mapped first to available technologies and then to design parameters through the use of the quality functional deployment (QFD) tool [3, Chapter 9]. The benchmark of competition is important for the selection (right wall of the House of Quality).

Secondly, the systematic search aims at encompassing the broadest range of potential ideas. It is however so that there is no longer any shortage of ideas; on the contrary, the opportunities in a product development project far exceed capacity [3, p. 50]. The problem has become merely that of idea and technology management: this is confirmed by the trend shifts in research on R&D from creativity aspects in the 50s to, among other things, idea and technology management [7]. Idea and technology management covers (1) synthesizing the past innovations (knowledge maps, patent compilation, technology books, see [8]), (2) developing inner idea incentive and filtering/maturity process, (3) focusing on innovation partnership and user innovation, and (4) managing customer feedback through customer relationships management (CRM) and after sales. (In automotive companies for instance, databases of car repairs and defects can be used to compute failure modes for a given engine technology or a given combination of technologies.) All this does not mean that systematic search cannot be used, but that it no longer needs to be considered as a central design activity.

The consequence of these arguments for the generic engineering design process model is important: these arguments show not only that it is not very well integrated into the funnel development model, that the separation between idea finding and concept design is doing more harm than good, but also that even as a stand-alone process, its use is problematic. The funnel development is one framework for product development among others. In the next section, we present alternatives and investigate the potential integration of the generic engineering design process model with them.

3. SPECIFIC DEVELOPMENT TACTICS

The funnel development has been the mainstream model for development of products. However, alternative strategies exist. Recall that the fundamentals behind the funnel development models were: early strategic decisions to avoid taking them during development; developing ideas and technologies during planning so as to avoid technological risk of failure; gathering as much information as possible on market and technology to have reliable information before development so as to avoid market risk of failure (technology and market strategy).

Models exist, however, that do not conform to the funnel development. Some show that these fundamentals are not necessary to ensure a successful development programme. They are presented in the first subsection. Others take into account specific development problems that the current process models do not tackle explicitly. They are presented in a second subsection. Some specific industrial cases, described in Section 3.3, have specificities not present in the current models. In all cases, the limits of the generic engineering design process model are exposed.

3.1. Relaxing the fundamentals of the funnel development model

Most development models emphasize the necessity to gather an exhaustive set of customer needs in order to be able to fully specify the design requirements. This would allow for a detailed planning of the development activities and thus decrease the market risk. However, this model minimises a recurring issue, namely market instability: the needs change during development time, new products appear, the consumer can scarcely express latent needs [10]. In a survey by Thomke and Reinertsen [11] involving more than 200 product developments, only 5% of the projects had established a complete product specifications list before beginning product design. On average, only 58% of the requirements were specified before starting the design phase. In response to that, Hamel and Prahalad [12] propose a radical alternative: expeditionary marketing. This consists in going to market as fast as possible (on a small scale) in order to acquire quick feedback. The product can then be modified based on a *very accurate* customer response. With this strategy the development manager accepts taking a higher market risk in exchange for the possibility to quickly enter the market. This strategy has been modelled and compared against the classical development model in [13]. Under certain circumstances, especially when there is an opportunity window, expeditionary marketing can be a better strategy. Some new problems can emerge, like that of branding: a product flop can be devastating for a brand. Here, too, different tactics can be developed. One is to launch a new product under a new brand, even if the introduction cost is high [14]. Another is to alter the name of the brand [15]. Tefal, developing a temperature indicator for its Teflon®-coated frying pans, used this technology first for babies' bottle heating systems where the company was a new actor. Once the technology was mature and well accepted, Tefal could launch on the frying pan market it was the leader of [16, 17]. Different branding strategies can be found in [15]. All in all, even a successful product can cause "brand dilution" as the values the brand stands for become less and less visible the more products it represents [18].

There are also strategies that allow for developing products while the technology is still not mature. Krishnan and Bhattacharya [19], for example, propose different alternatives. Let us suppose that a company has the choice between a mature technology and a superior, but less mature, technology. The company can decide to launch two product development projects where two variants of the same product are developed in parallel. At each design review, depending on the maturity of the second technology, the company can decide to abandon one of the product development projects. This implies higher development costs, but the advantages are numerous: if the new technology does not work at all, the only lost costs are those associated with those parts adapted to the new technology (the development cost for this technology would have been undertaken during planning anyway). If the new technology development takes time, a product still gets to the market, and a new one with the working technology can come very quickly later on. And if the technology works, the new product is expected to present added value that will differentiate it from competition and increase profits that will outrank the parallel development costs. Another flexible development strategy would be to design the parts linked with the two technologies so that the product will interface with both technologies. In that case, variable manufacturing costs will increase due to this modularity, but unlike the precedent approach, the later phases of product design and production design will be less costly as only one version of each part is developed. Once again, instead of trying to minimise risk, the strategy is to reason in terms of alternatives.

The problem linked to strategic decisions during development can also be apprehended differently. Hatchuel and colleagues [20] propose inserting an "innovation" function between the research and development functions. The research department generally has little knowledge of the market realities and does not know how to prioritise research efforts. On the other hand, engineers in the development department may not know where to look for and test new principles. In this Research-Innovation-Development (RID) framework, an innovation department (I) makes the link between the need for research or technology development (R) and product development (D). The innovation team represents a task force that has knowledge about the company's development, marketing and technology strategy. It can decide during a product development project that the research department can investigate quickly some technology that is of importance for a particular project and fits with the company's strategic profile, or determine how it will change the company strategy.

In these three setups, *fundamentally different from the funnel development model*, the generic engineering design process model does not fit well either. The first case, expeditionary marketing, is about going as fast as possible to the market, leaving little time for systematic search, combination and selection. In the second case, some critical technologies are chosen and the product development project is planned around them. In this setup, much of the function structure is determined, the technology development part is research-based and the remaining development activities (e.g. modularisation) concern mainly embodiment design. Finally, in the last case, the design process is hardly described as a systematic search, but more as an investigation into the sense of the Design Rationale framework [21] or the CK theory [22].

3.2. Focusing on specific constraints

Within the funnel development model, or compatible with it, some works have dealt with specific (although still quite common) cases of product development. The generic engineering design process model does not address many of these cases explicitly, which makes it hard to apply to them.

One of the four types of product development project evoked in Wheelwright and Clark [3] and Ulrich and Eppinger [5, pp. 35–36] is the development of a new product (also called core product, platform or next-generation product). This is a product that is thought to be the basis for a new product family, and to open new markets for derivatives [3, pp. 95–96]. As discussed in Tabrizi and Walleigh [23], the development of these products must be carried out together with the planning of the derivatives. Indeed, if such a next-generation product opens a new market, then the company needs to surround this "blue ocean" [24] and block all possible entries by competitors in order to stay dominant. Developers have to take care of modularity very early in the process and not during the system-level design or embodiment design phase. It is also sometimes necessary to apply the novel functions or product attributes over several product generations: Consumers may be resistant to very new products; it is also important to be ahead of the competition by regularly upgrading existing products. This strategy was used successfully for Sony's Walkman. Sony stayed ahead of the competition by regularly presenting new improvements that had been planned in advance. This approach is contradictory to the classical concept selection, which is based on choosing the "best" alternative. Derivatives are not only derived versions of the original product, they are also complementary products. Additional examples are iPod and iStore. Thus planning and design specifications of those complementary products need to be done conjointly with the core products. This activity of co-ordination among projects and synergy is scarcely addressed in the generic engineering design process model.

Another specific case is the one linked to *breakthrough products* [3] or *radically innovative products.* Innovative is to be understood according to the OECD definition of innovation, that is, using working principles or processes not mastered by the company: "An innovation is the implementation of a new or significantly improved product (goods or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations. [...] The minimum requirement for an innovation is that the product, process, marketing method or organisational method must be *new (or significantly improved) to the firm*." [25, p. 46, emphasis in original]. The market may also be unknown to the company. This case is also similar to that of start-up companies [16,17,26]. The company's technology and market strategies are of little use, it is essential to quickly receive relevant information, to focus on what yields the most value in the product and minimise the technological risks for the auxiliary components, to get feedback from the market through strategies similar to expeditionary marketing, to converge quickly to a satisfactory (not optimal) solution, etc. The specifications are created throughout the development process: some parts need systematic search, some don't, and the activities of planning and development are confounded.

It was mentioned above that some projects have interdependences and require synergies. The whole product development organisation greatly influences the design process. In many cases, the company is no longer in charge of the development of many of the product subsystems. The company focuses on core competencies and outsources the rest. Sometimes, only the technical function is described and left for development by the supplier. In case of alliances, virtual or extended enterprises [27], or deep partnership with suppliers, part of the product is developed outside the company. It is no longer possible to develop, or search for, an optimal product with function structures and morphological matrices. In case of merging or acquisition, it is necessary to get to know the new organisation, build trust, get acquainted with new technologies and integrate them. Completely different design challenges are at stake, like for instance managing design decisions postponement within partners or the strategic supplier selection issue.

3.3. Case studies in industry

The objective here is to provide some examples from industry in support of the findings presented above. The first case is an example from a research project in which the interaction between a product and its packaging was studied. The goal of the project was to survey the need for an integrated product and packaging development process — see Bramklev et al. [28]. In one of the 60 companies participating in the survey, it was found that when delivering its new gasoline pumps to some of the countries belonging to the “emerging market” in Europe, severe damages were inflicted to the pump during transport and handling. The reaction from the company, situated in Sweden, was to improve the design of the pump to meet the severe conditions during transport and handling. The result was a much more expensive product which was over-dimensioned for its ordinary use. After contemplating alternatives to the redesign, it was decided that the packaging should be improved, thus allocating some of the supportive functions to the packaging instead of the product. This alternative was later adopted, resulting in an increased understanding of the necessity to plan for these situations early on in the development process as well as the necessity to fully integrate the design and development of product and packaging. There was at the time no support in any published development process for an integrated approach to product or packaging development.

The second case is the one of a complex product: a car. Usually, dedicated development plans exist in a company that are based on a number of business engineers’ interrelated specific plans. These specific plans contribute to the realization of a number of pre-existing functions. This means that a functional structure already exists at the beginning of the project and products are developed within this generic structure. If a new structure is to be developed, it is not a part of a product development project but rather in the product planning phase or in any other framework. Implication: function structures are never used as a part of the conceptual design phase in any product development project. In addition, there often exists a mechanism of consistently selecting a few mature technological ideas to put into the new vehicle project (e.g.: the door lock without a physical key, the removal of the hand brake...). Consequently, the major part of ideation (apart from the overall concept) is directly imported into the development project.

4. DISCUSSION AND CONCLUSION

The different contexts of the engineering design activity presented above show that the systematic engineering design process model is not as generic as intended. In most cases, different steps must be skipped or are not adapted to the situation. Of course it is often emphasized in the literature that these design models have to be used more as guidelines than by-the-book. But we hope to have shown that even the fundamentals are to be questioned. Most of the time, the object of design is neither a broad search for solutions nor a quest for an optimal product. In many cases there is no shortage of ideas; the problem is so constrained that there are few degrees of freedom left for systematic search (at least at the conceptual level), and finding one solution is satisfying.

Why is there such an inadequacy? One early reason for a systematic design process was that it was supposed to support *a* rather isolated engineering designer and prevent him/her from jumping onto an early solution and thus avoid making design mistakes. The design work did not necessarily cover a complete product but mostly subsystems, as witnessed in the numerous examples in [2, 29, 30]. The systematic design process models concerned mainly mechanical engineering design, which also restricted the scope of application. Moreover, prior to the 70s, sequential product development was the rule, which allowed for isolated, out-of-context design work. Finally, although the different activities of engineering design were presented as a process, it was emphasized that most activities happened in parallel; see especially Koller [29]. Under that reduced setup the design process model makes more sense — although it still has some coherence problems; see [31]. Integrating the engineering design process stages as development phases has caused many of the problems reviewed in this document.

Other problems are also present because the first design process models focused more on industrial (business-to-business, or B2B) products or only on the technical parts of consumer (business-to-consumer, or B2C) products. To that end, the focus has been towards defining exhaustive requirement lists for a well-defined industrial client. On the other hand, the product planning model focuses mainly on consumer products, where it is important to determine what the market wants, that is the common denominator of a certain set of customers. The focus is then on finding the few critical attributes needed to differentiate the next product from competition. Then a QFD is better adapted than the task clarification and systematic search. Adopting a planning phase devoted to consumer products and a design process developed for B2B systems led to some of the incompatibilities mentioned above.

Finally, the development environment has evolved since the first design process models were developed, and some current situations were simply nonexistent a few decades ago.

What this synthesis also shows is that the funnel development model is not the panacea either. Several strategies cannot be seen as derivatives of the funnel development model. There are different contexts that call for different methods and strategies.

This review has dealt with the shortcomings linked to the application of the systematic engineering design process in the context of product development. It rejoins the different criticisms that have questioned the fundaments of systematic design: In [31], some inner incoherencies of the systematic approaches were highlighted; in [32], the discrepancies between prescriptive models and descriptive models were developed and tested — the efficiency of the prescriptive models was severely challenged. All in all, this calls for a deep reflection on the further development of methodological support to the engineering design activity.

REFERENCES

1. Motte, D., Bjärnemo, R. and Yannou, B., “On the integration of engineering design and development process model — Part I: Elaborations on the generally accepted process models”, 3rd International Conference on Research into Design — ICoRD’11, 2011.
2. Pahl, G., Beitz, W., Feldhusen, J. and Grote, K.–H., “Engineering Design – A Systematic Approach”, (3rd Edition), Springer, 2007.
3. Wheelwright, S.C. and Clark, K.B., “Revolutionizing Product Development”, Free Press, 1992.
4. Cooper, R.G., “Predevelopment activities determine new product success”, Ind Mark Manag, 17, 237–248, 1988.
5. Ulrich, K.T. and Eppinger, S.D., “Product Design and Development”, (4th Edition), McGraw-Hill, 2008.
6. Rianantsoa, N., Yannou, B. and Redon, R., “Concept-to-value: Method and tool for value creation in conceptual design”, 36th Design Automation Conference - DETC/DAC’10, 2010.
7. Larson, C.F., “50 years of change in industrial research and technology management”, Research Technology Management, 50, 26–31, 2007.
8. Angéniol, S., Yannou, B., Longueville, B., Chamerois, R. and Gardoni, M., “Supporting saving ideas reuse with an ontology based tool”, 18th International Conference on Design Theory and Methodology — DETC/DTM’06, 2006.
9. Cooper, R.G., “A process model for industrial new product development”, IEEE Trans Eng Manag, EM–30, 2–11, 1983.
10. Mohr, J., Sengupta, S. and Slater, S., “Marketing of High-Technology Products and Innovations”, (2nd Edition), Prentice Hall, 2005.

11. Thomke, S. and Reinertsen, D.G., "Agile product development: Managing development flexibility in uncertain environments", Calif Manag Rev, 41, 8–30, 1998.
12. Hamel, G. and Prahalad, C.K., "Corporate imagination and expeditionary marketing", HBR, 69, 81–93, 1991.
13. Motte, D., "Study of alternative strategies to the task clarification activity of the market-pull product development process model", 21st International Conference on Design Theory and Methodology — DETC/DTM'09, 2009.
14. Brown, P.B., Schiller, Z., Dugas, C., Scredon, S. and et al. "New? Improved?" Business Week, 2917, 74–76, 1985.
15. Aaker, D.A. and Keller, K.L., "Consumer evaluations of brand extensions", J Mark, 54, 27–42, 1990.
16. Le Masson, P., Weil, B. and Hatchuel, A., "Les processus d'innovation — conception innovante et croissance des entreprises (In French)", Hermès-Lavoisier, 2006.
17. Le Masson, P., Weil, B. and Hatchuel, A., "Strategic Management of Innovation and Design [tr. from Les processus d'innovation — conception innovante et croissance des entreprises]", Cambridge University Press, 2010.
18. Pitta, D.A. and Katsanis, L.P., "Understanding brand equity for successful brand extension", J Cons Mark, 12, 51–64, 1995.
19. Krishnan, V. and Bhattacharya, S., "Technology selection and commitment in new product development: The role of uncertainty and design flexibility", Manag Sci, 48, 313–327, 2002.
20. Hatchuel, A., Le Masson, P. and Weil, B., "From R&D to R-I-D: Design strategies and the management of "innovation fields"", 8th International Product Development Management Conference — IPDMC'01, 415–430, 2001.
21. Bracewell, R., Wallace, K.M., Moss, M. and Knott, D., "Capturing design rationale", Computer-Aided Design, 41, 173–186, 2009.
22. Hatchuel, A. and Weil, B., "A new approach of innovative design: an introduction to C-K theory", 14th International Conference on Engineering Design — ICED'03, 2003.
23. Tabrizi, B. and Walleigh, R., "Defining next-generation products: An inside look", HBR, 75, 116–124, 1997.
24. Kim, W.C. and Mauborgne, R., "Blue Ocean Strategy", HBS Press, 2005.
25. OECD, "Oslo Manual — Guidelines for Collecting and Interpreting Technological Innovation Data", (3rd Edition), Organisation for Economic Co-operation and Development, 2005.
26. Silberzahn, P., "The Determination of its Products and Markets by the Entrepreneurial Firm: A Socio-Cognitive Model (in French)", PhD Thesis, École Polytechnique, Paris, France, 2009.
27. Browne, J. and Zhang, J., "Extended and virtual enterprises — similarities and differences", Int J of Agile Manag Syst 1, 30–36, 1999.
28. Bramklev, C., Bjärnemo, R. and Jönson, G., "Concurrent design of product and package — Extending the concept of IPD", 13th International Conference on Engineering Design — ICED'01, WDK 28, 2, 377–384, 2001.
29. Koller, R., "Engineering Design Methods for Mechanical Engineering, Precision Engineering and Process Engineering (In German)", Verlag, 1976.
30. Rodenacker, W.G., "Systematic Design (In German)", Springer, 1970.
31. Motte, D., "A review of the fundamentals of systematic engineering design process models", 10th International Design Conference — DESIGN 2008, DS 48, 1, 199–210, 2008.
32. Bender, B., "Successful Individual Design Process Strategies in the Earlier Phases of Product Development (In German)", PhD Thesis, Fortschritt-Berichte VDI (Reihe 1, Nr. 377), Fakultät für Verkehrs- und Maschinensysteme, TU Berlin, Berlin, 2004.