INTERNATIONAL DESIGN CONFERENCE - DESIGN 2004
Dubrovnik, May 18 - 21, 2004.

A STANDARDISING APPROACH TO DESCRIBE AND TO COMPARE DESIGN MODELS FOR MECHATRONICS

S. Möhringer

Keywords: design methodology, design models, design proceeding, strategies and methods, mechatronics, domain-specific influence on design

1. Introduction

Design models are recommendations for action. They assist the designer during the proceeding and help him to recognise the situation and the corresponding steps to go. Design models are influenced by different engineering cultures and point of views in research. Blessing [Blessing, 1996] compared descriptive and prescriptive models within the mechanical engineering design. In mechatronics the situation is still more complex. The design is worked out synergistically by the three domains mechanics, electronics and information technology which are characterised by their own ways of thinking, nomenclatures and experiences. Therefore a huge variety of design models exists, however hardly any mechatronic-specific design model in a cross-domain sense. Existing mechatronic-specific design models are often modified design models of one domain, e.g. the popular v-model of software engineering [Rothfuß et al., 2002], the design model of mechanical engineering [Kallenbach et al., 1999] or the proceeding in control engineering [Isermann, 1996]. An established mechatronic-specific model integrating the domains in a cross-domain and equal treated way is missing.

2. Research objectives

In order to come to an understanding within the different domains and to develop a common design proceeding systematically, it is necessary to know the differences and the common points of the domain-specific proceedings. Design proceeding can be visualised in different ways, e.g. as phase-milestone-diagram (VDI 2221), as v-shape (v-model of software engineering) or as y-model (electronics). Each visualisation tries to point out special aspects. Facing the number of existing design models and their heterogeneous representation it is difficult to identify and to compare the particularities.
It is the objective:

- to develop a standardising approach to describe and to compare design models
- to extract and visualise the particularities of the different models clearly
- to analyse the main differences of design models in the context of mechatronics
- to suggest a cross-domain proceeding for mechatronics treating equally the involved domains.

A more detailed description can be found in [Möhringer, 2003].

3. A standardising approach to describe design models

The specific graphical representation of the design models is transferred to a standardised representation. In order to increase the degrees of freedom the two-dimensional design model is transferred to a three-dimensional design space, e.g. [Grabowski, 1997]. It consists in a cube (imaginary design space) with the following 3 dimensions (fig. 1):

1) **phases** (or design steps),
2) **results** of these phases (as product states) and
3) a **specific dimension** which can be marked differently e.g. product maturity, processes or view levels.

The design process runs as a sequence of activities (represented as balls) within this cube. For each activity the designer can be supported by methods and tools. Arrows are connecting the activities and show the proceeding direction. The design strategy e.g. cyclical, sequential etc. can be visualised as a big arrow. Iterations are represented as dotted lines. Process modules can be created bundling a sequence of activities. Such process modules are useful when activities are processed repeatedly.

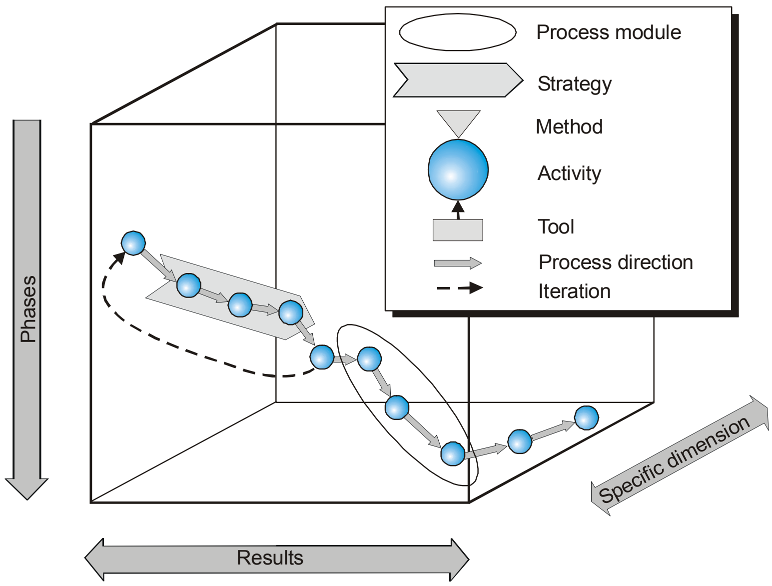

Figure 1. Standardising approach to describe design models

With the help of these graphical constructs as shown before, the essential properties of different design models can be represented in a standardised way. The approach is applied to well-known design models.

4. Verification of the standardising approach by comparing design models

The design models of mechanics (VDI 2221: represented as a phase-milestone-diagram [VDI 2221, 1993]) and of electronics (y-model: represented as a circle with an integrated "y" [Rabaey, 1996]) are well-known and internationally accepted design models for both domains (the original design of both models isn't shown for lack of space). They look quite different at first site. After being transferred into the standardised form there are very little differences.

The **design process in mechanics** (fig. 2) is divided into main phases which contain further working steps. The working steps lead to results forming the base for the next working steps. This structure corresponds to the macro-level of systems engineering [Daenzer and Huber, 1994]. As third dimension the proceeding can be characterized by view levels; depending upon phase and working step a change takes place between the views. In the early phases of product planning and task clarification all view levels – although on an abstract level – are gone through. During conceptual design the proceeding concentrates mainly on the function and behavior view, during embodiment and detail design the emphasis lies on the structure and the shape view. On the micro level (activities, operational instructions for the designer) the problem solving cycle is referred to. Furthermore methods are provided to support the working steps.

The **design process in digital electronics** (fig. 3) – although more formal and partly automated – resembles very strongly the proceeding in mechanics. This becomes clear when comparing the models in standardized representation (fig. 2 and fig. 3). The three views of the y-diagram according to Gajski/Kuhn [Rabaey, 1996] form the third dimension. After the specification which includes all three views, the system design starts on the behavior level and leads with refinement and synthesis steps to the layout/physical design on geometry level. Of course the pure top-down procedure cannot always be maintained; as well as in the VDI 2221 returns (abstraction, extraction) and repetitions of design steps are possible. The main difference in comparison with mechanics lies in a stronger formalization:

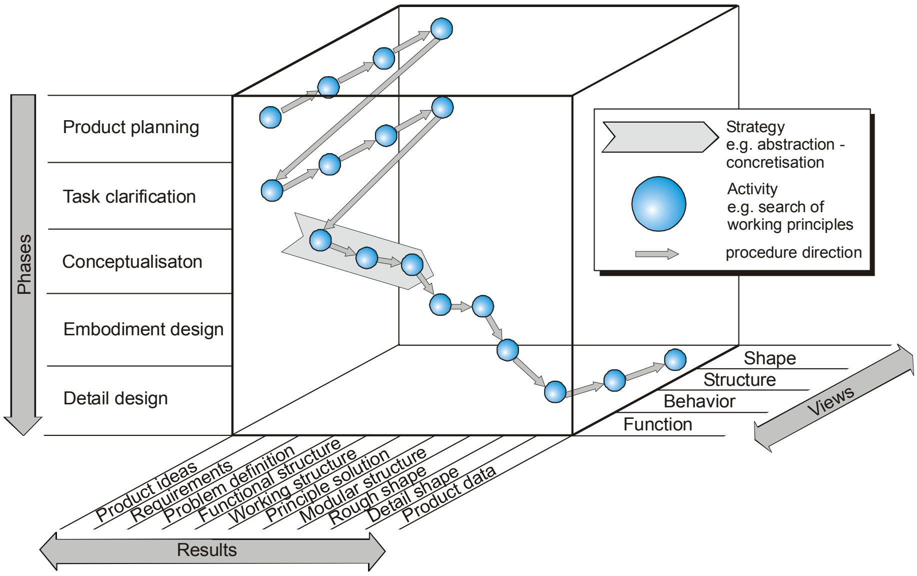

Figure 2. Proceeding in mechanics, according to [VDI, 1993]

During logical design for example, mainly existing components (transistors, capacities, resistors) are used while the embodiment design in mechanics comprises many variables (dimensions, material, manufacturing methods etc.) and is characterized by numerous iterations. Therefore the micro-level (situation-specific action guidance of the designer) is less important in electronics.

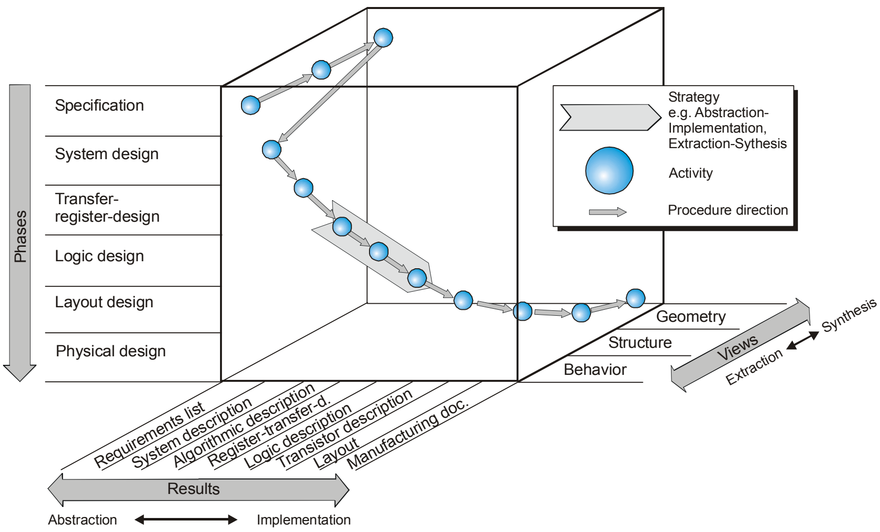

Figure 3. Proceeding in digital electronics, according to [Rabaey, 1996]

In **software engineering** different procedure models are used. The comparison is exemplified by the well-known v-model and the proceeding in object-based software engineering. The standardising approach shows the differences. The **v-model** has an integrated strategy to follow, i.e. a hierarchical proceeding via levels (fig. 4): top-down from system to module level during analysis and design, bottom-up to system level during realization and integration. Two strategy options are offered:

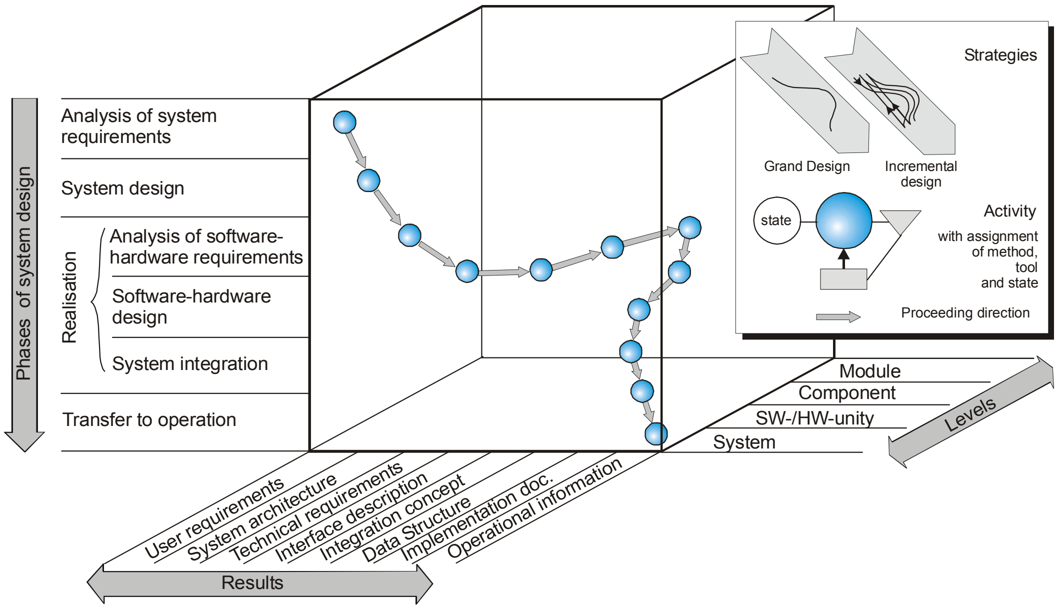

Figure 4. Proceeding in software engineering, according to v-model [v-model, 1997]

"Grand design" means a single phase procedure to the finished system, " incremental design" a stepwise design based on refined user requirements.

The model of **object-oriented software engineering** (fig. 5) has as well a particularity: The design process runs with several iterations which are implemented as processes (third dimension – the processes analysis, design, realisation, test).

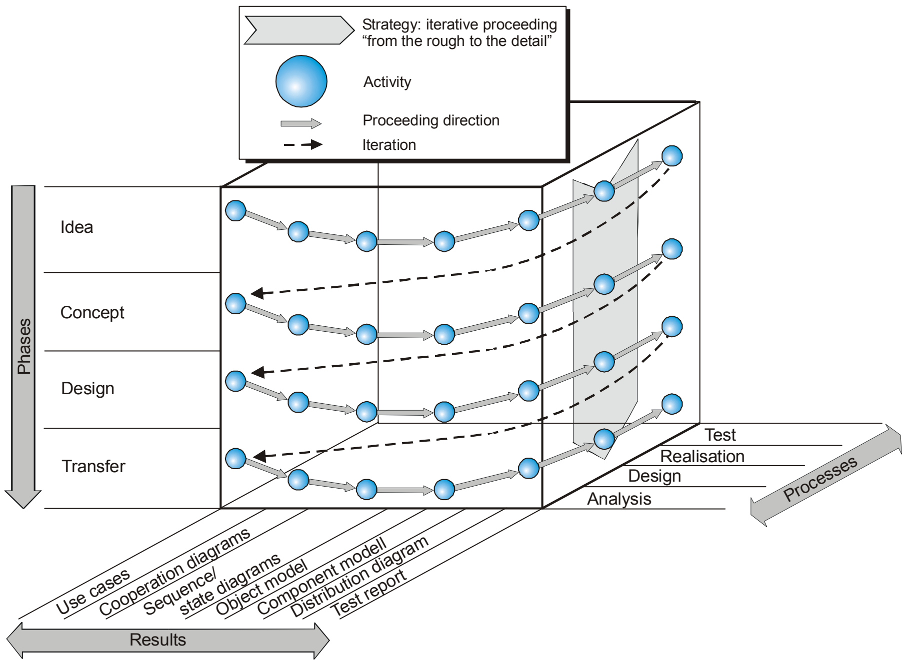

Figure 5. Proceeding in object-oriented software design, according to [Jacobson et al., 1996]

Every iteration ends with a verification (review) which initiates the next process. The model has an inherent strategy "from the rough to the more detailed design": with every process the system becomes larger and more concrete. The object-oriented procedure model includes a macro-logic (phases and results) and a micro-logic (iterative processes).

The transformation of the exemplified four design models into the standardising form shows:

- Phases and results are dimensions which occur in every design model. Transferred into a standardised graphical representation the design proceeding can be visualised more vivid.
- The third dimension can be chosen to represent a specific focal point of the proceeding. If two design models allow to chose the same dimension e.g. views the similarity becomes obvious (see proceeding for mechanics and electronics). If the comparison is made based on the original model representations (phase-milestone-diagram and y-model) the similarity is not at all obvious.
- If the representation of a design model visualises the common proceeding in a more vivid way the cross-domain acceptance of a model can be improved. This is especially important for mechatronics.
- Therefore the standardising approach seems to be an appropriate method to analyse and to visualise design models in the context of mechatronics.

5. Results and Suggestions

The comparison of the procedure models used by the domains mechanics, electronics and software engineering leads to two main observations:

1. The exemplified models support mainly the macro-level by structuring the design process into phases/activities and by assigning results. The micro-level is only marginally taken into account, strongest within the object-oriented software design. However especially on the micro-level there is a need in mechatronics. E.g. the partitioning is a very demanding task: principle solutions and components from different domains need to be selected and their interactions need to be checked. Concrete action support would be very useful for the individual designer and the multi-disciplinary team.
2. The proceeding within the involved domains differs – from the macro point of view – only slightly: The design in mechanics and electronics runs very similarly. As third dimension the views function, behavior, structure and shape are chosen for the model of mechanics, the views behavior, structure and geometry are chosen for the model of electronics. The proceeding in electronics is more formal but the principal macro-logic of proceeding is similar to mechanics. The v-model differs because of the given hierarchy levels. The strategy (hierarchical proceeding via levels; chosen as third dimension) is implemented while in the models of mechanics and electronics it is up to the designer to chose the appropriate strategy. The object-oriented proceeding provides integrated process iterations and includes therefore the micro-level as well.

On the macro level it appears therefore feasible to conceive a **cross-domain procedural model for mechatronics**. The common two dimensions of all domains are phases/activities and results (the character of the models is result-oriented). The third dimension has been formed by views/levels (in mechanics, electronics and the v-model). Only the object-oriented model uses additionally processes. In order to support the micro-level in a stronger way a cross-domain model for mechatronics should give up the dominant result-orientation and integrate micro-processes as one dimension. The object-oriented model seems to be a good example to do similarly.

6. Conclusion

A variety of design models, coming from the involved domains, influence the proceeding in mechatronics. The proceeding can be visualised in different ways. Each visualisation tries to point out special aspects. Facing the number of existing design models and their heterogeneous representation it is difficult to identify and to compare the particularities. This contribution introduces a standardising approach to describe and to compare design models. Thanks to the graphical representation in a cube, three instead of normally two dimensions can be visualised. The points in common and the differences become obvious much faster. The comparison shows very little differences on the macro-level of design models. They structure the design process in phases/activities and related results. The differences, mainly implemented design strategies, can be visualised as third dimension. Therefore a cross-domain design model for mechatronics integrating the specific strategies as third dimension seems to be a promising representation to be accepted by all the involved domains. The models provide hardy any support on the micro-level. There is a special need for mechatronics (e.g. concrete action support for partitioning) which is not yet fulfilled sufficiently. A cross-domain design model for mechatronics should provide supporting elements on the micro-level, e.g. iterative processes, verification procedures etc.

References

Blessing, L.T.M.: "Comparison of design models proposed in prescriptive literature". In: The role of design in the shaping of technology, proceedings from the COST A3 and COST A4 workshop, Lyon, France, 3 – 4 February 1995, Office for official publications of the European Communities, Luxembourg, 1996.

Daenzer, W.F.; Huber,F.: "Systems Engineering – Methoden und Praxis", 8. verbesserte Auflage, Verlag Industrielle Organisation, Zürich, 1994.

Grabowski, H.: "Modellieren – Neue Verfahren der Produktentwicklung". In: Schuh, G.; Wiendahl, H.-P.: Komplexität und Agilität: Steckt die Produktion in der Sackgasse? Springer-Verlag, Berlin et al., 1997

Isermann, R.: "Modeling and Design Methodology for Mechatronic Systems". In: IEEE/ASME Transactions on Mechatronics, vol. 1, no. 1, 1996

Jacobson, I. et al.: "Object-Oriented Software Engineering - A use case driven approach", Addison-Wesley, 1996.

Kallenbach, E.; Saffert, E.; Schäffel, Chr.: "Multi-coordinate Drive Systems – Opportunities and Limits", 3rd International Heinz Nixdorf Symposium, May 1999, Paderborn, Proceedings pp. 11-24

Möhringer, S.: "Entwicklungsmethodik für mechatronische Systeme", Habilitation, Universität Paderborn, Paderborn, 2003 (Habilitation submitted).

Rabaey, Jan M.: "Digital Integrated Circuits, A Design Perspective", Prentice Hall Electronics and VLSI Series, 1996.

Rothfuß, R.; Lasa, M.; Heinkel, H.-M.; Tirgari, P.: "Systems engineering in the design of mechatronic systems". In: International Journal of Vehicle Design, Vol. 28, Nos. 1/2/3, 2002, pp. 18 – 36

VDI 2221: "Systematic approach to the development and design of technical systems and products", Beuth Verlag, Berlin, 1993.

V-model: "Design standard for IT-systems of the German Government"; General Directives (250, 251, and 252) describing procedures, methods and functional requirements for tools to be used, http://www.v-modell.iabg.de/vm97.htm#ENGL, 1997.

Dr.-Ing. Stefan Möhringer
Simon Möhringer GmbH, Industriestrasse 1, D-97353 Wiesentheid, Germany
Telephone: ++49-9383-95029, Telefax: ++49-9383-95015
E-mail: stm@moehringer.com