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WHAT HAPPENED TO DFM? - 17 YEARS DFX-SYMPOSIA

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Abstract

Design for manufacture was the master example of DFX-efforts in the 80'ies, and a popular topic at design conferences. Since then the visibility in the research world has vanished, and the spread in industry seems to be stagnant. Yet the methodology has kept its importance in highly cost-competitive industries like the car industry.

The DFX-Symposia arranged by the Lehrstuhl für Konstruktionstechnik by Friedrich-Alexander-Universität Erlangen-Nürnberg since 1990 had originally DFM as core area, and many important and original research results was launched at these symposia. What is the role of DFM today? Has it been absorbed in abilities of modern design support systems? Is it a given ability of engineering candidates to master DFM? Where do we find the methods?

In the 80'ies the DFM methodology was seen as a corrective effort. A design proposal is analysed for the goodness of producability and assemblability (often based upon a knowledge base) and a numerical score is given, together with advice on how to make it better. Today's situation of competition forces companies to severely proactive efforts of finding optimal production methods and therefore to fit the products carefully to these methods. We see companies perform multi-product development based upon modularisation and platform thinking.

The development of the DFX-Symposia is mirroring what happened to DFM: Computer support, management of knowledge, information and data, a more comprehensive view upon DFM as part of multiple DFX and part of total product life considerations and concern about sustainability, are some of the directions in which DFM has moved. The paper postulates and points out the central role of DFM in the design of product architecture and modules and the importance of high level alignment and strategic thinking leading to a proactive, controlled optimisation of the production.

1 Background

Design for Manufacture emerged in the early 80'ies in USA, Europe and Japan in parallel activities. Together with Design for Assembly the application of the principles in industry leads to surprising results like substantial parts reduction, simplification of assembly, and radical cost reductions. Design approaches for quality, cost and environment emerged gradually showing the same basic structure as DFM and DFA, Andreasen [1], Bauer [17]. Reports from international conferences [2,3] show that the DFX-area is gradually disappearing from the research agenda, and industrial interest for DFM and DFA seems to have stagnated.

In this paper we will shortly define some basic concepts related to DFM, and sum up what we believe are basic theory elements. DFM may be seen as a means for integration of design and manufacture, therefore integration efforts and DFM has developed in a parallel pattern. We draw a line of steps in the development and application of DFM, and finally we show the role of DFM in modularisation and platform thinking, supported by industrial examples. The paper is not a review of the DFM area and its contribution. It is also not a fair balance of the content and role of the DFX symposia. But the importance of the symposia shall not be underestimated as a forum for exchange of ideas and a scene for presenting daring new thoughts.

2 Some definitions

The following considerations are general for all DFX-areas, and therefore we use the DFX notation. DFX has two meanings. ‘X’ may stand for a product property (like cost, quality etc.) or for a product life phase activity. Cost elements occur in all life phases, and other properties are more locally positioned like assembly lead time, therefore the so called DFX-matrix [1] in Fig. 1 will not be fully filled out if we try to map all what is in focus in a concrete project.

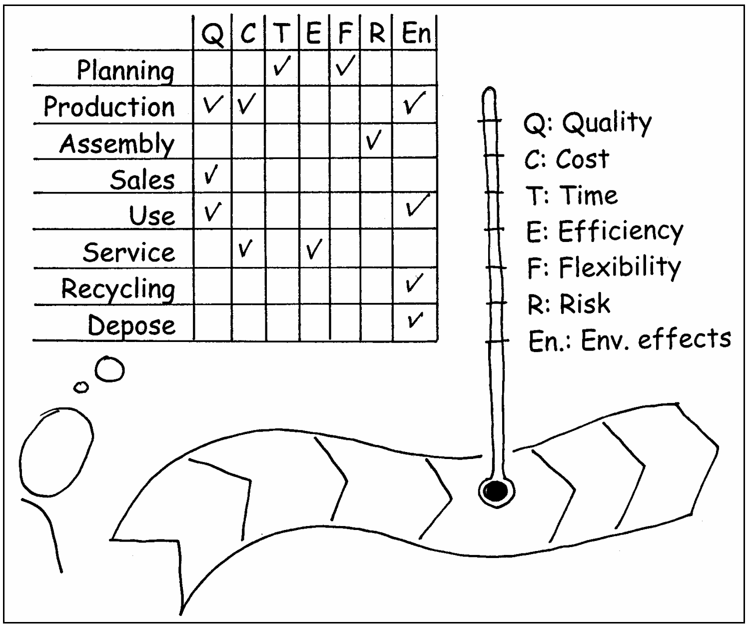

Fig. 1: The DFX matrix is related to the “universal virtues”, i.e. the criteria for activity goodness [1].

DFX means to fit the product to certain life activities and focusing upon certain properties (“universal virtues”, Olesen [4]) related to this activity. In the efforts to create an integral organism the company will try to coordinate efforts for optimising supply, production and delivery by fitting these activities to the products and vice versa, and to fit the products to the users life phase activities like use, maintenance and disposal.

DFX may therefore be seen as the design efforts to make a *double, coordinated synthesis*, namely to synthesise the product and to synthesise certain activities and systems in the product’s life. Kimura and Suzuki [5] provoke us by underlining the importance of real and innovative insight into the product’s life activities by saying, “.. to first design total product lifecycle in order to make reuse/recycling activities more visible and controlable, and then to design the products appropriately, to be embedded in the cycle“.

The core of a DFX area is a *set of principles*, which tell how to design the product in accordance with these activities and systems. Normally the principles are related to statements about what happens if the principle is followed, for instance “Use of unidirectional assembly allows the use of simple assembly units and therefore lead to low cost assembly”

[6]. It is important to note that these principles are *conditionally valid*, i.e. that there may be situations, where a principle is not giving any positive effect or may even lead to negative effects.

Fitting the product to its life activities is a multi-stakeholder and multi criteria search for the best solution, normally leading to more or less conscious trade-off. Best solution is not just a good product, but a short and long term contribution to the company's business and maybe an enhancement of certain company functions, like new assembly cells, a new material supplier, or a new partner for sales in India. In some literature the DFX principles are seen as criteria, for instance that uni-directional assembly should be seen as a criteria for ease of assembly. We should warn about this interpretation. Creating a uni-directional assembly is only a good solution, if this principle lead to influences on criteria like cost, time or efficiency, see Fig. 1.

3 DFM Theory elements

In 1997 at the 8. Symposium, we presented a paper on "Basic thinking patterns and working methods for multiple DFX" [1], a paper which has since been widely used in our education. The paper presented 7 basic elements of insight, which might be seen as theory elements, see Fig. 2.

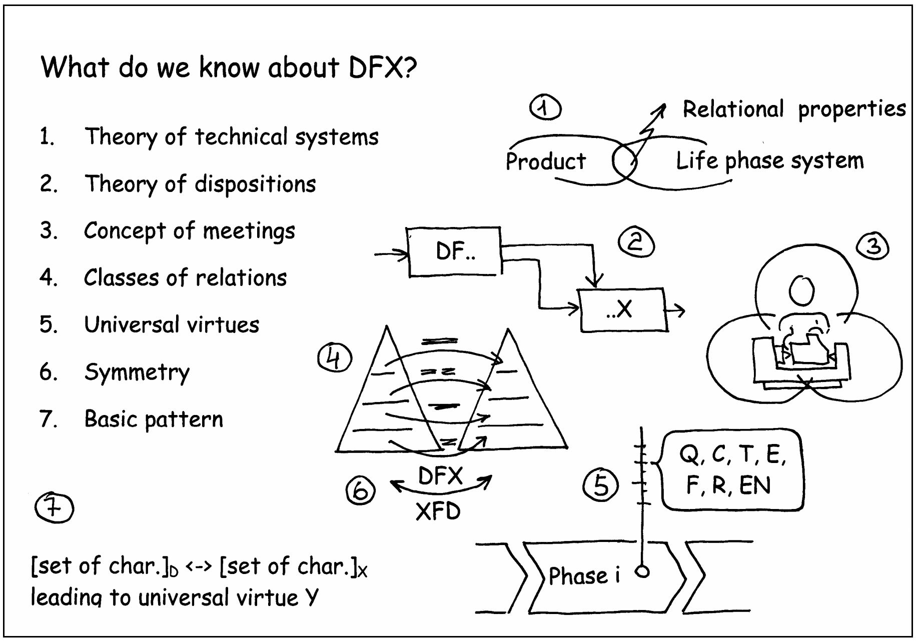

Fig. 2: Overview on what we see as elements of a theory of DFM [1].

1. *Theory of technical systems* [7]. This theory is the basis for identification of the characteristics of artefacts and activities and establishing the knowledge about the relations between the product or design and the life phase systems, Hubka [8], [6,9,10,11,18].

2. *Theory of dispositions*, Olesen [4]. This theory explains to us, how the design activity influences the nature and efficiency of the following realisation activities.

3. *Concepts of meetings* [8]. Many properties normally seen as product properties are actually relational properties, i.e. the properties shows up and are dependent on an activity, in which the product, a certain product life system and some operators are acting. We call this aggregation a *meeting*. Manufacture cost is a typical relational

property, depending upon the design and a long list of more or less automated operations in the production system.

4. *Classes of relations*, Fabricius [11]. Both the product and the mentioned systems may be seen as hierarchical structures. Their relations may therefore also be seen on many levels. It means that there for the manufacturing area are DFM relations between the product and the production system on levels of product structure vs. production layout, product modules vs. production cells, and components vs. manufacturing processes. High level relations are most influential [11].

5. *Universal virtues* [4]. It is a surprising fact that literature has many proposals for classes of product properties, Hubka [7], Pahl & Beitz [12], but very few for activities. Olesen launched the concept of *universal virtues*, which are important classes of properties, which characterise the goodness of an activity. The DFX matrix Fig. 1 is based upon these classes.

6. *Symmetry*. As mentioned above, the fitting or alignment shall be seen as a mutual effort. The designers shall fit the products to good manufacture and manufacture shall offer design good processes and assemblies mature for reliable and good products.

7. *Basic relational patterns* are the principles or rules identified by industrialists and researchers. These principles may be on high level concerning structural aspects, or on low level concerning specific component and process aspects.

In the following we will take a closer look at the development over time of DFM and how the approaches and methods utilise the elements above.

4 Integration efforts

Design for manufacture and integrated (concurrent, simultaneous) engineering or product development may be seen as respectively the tool and the procedure in which this tool shall be applied. Design and production in a modern industrial company is of course fully disintegrated in time, location and manning. Therefore it is a metaphor when we speak about integration of design and manufacture. What do we mean?

The interdependency between the design activity and production is described by the theory of dispositions, Olesen [4], saying that the design activity not only determines what shall be done in manufacture, but also to a high degree how and how efficient we can produce. Integration therefore means a mutual fitting of the design activity (leading to a good product) and the production activity (leading to effective, cheap production), based upon a correct, flawless and quick communication. The integration has as a prerequisite that there should exist a higher level set of criteria telling how to balance design efforts (directed to the customer) and the production efforts (company internal matters mainly).

How this integration is established and how it has been established over time is a core theme of DFM. For the purpose of articulating the degree and pattern of integration we need a mapping or framework. We will create this by looking upon the means for integration applied through time and in this way reach to the means for integration, which characterise DFM today.

Step 1: The stable world

Early publications which we today would call DFM contributions, but which at that time was the core of "Konstruktionslehre", shows advices in the form of "correct/incorrect". A typical publication is by Matousek [13]. The form is mirroring a stable world where products are followed by well-known, established production methods and it is expected, that engineering candidates know about “all” production methods. In this period there are no problems in following sequential models of designing, because of well-known relations and solutions.

Step 2: Industrial expansion

In the 60ies and 70ies we experienced industrial expansion, „everything produced can be sold“. Many new technologies emerge, new types of products, mainly electronical, fill the markets and many specialised production methods are applied. The processes lead to “over the wall”-feeling in production: The designers leave it to production how to produce the products, Ehrlenspiel [14]. Typical integration means in this period is the use of up front specifications, very detailed, instructive design procedures, and many attempts for standardisation and group technology approaches.

Step 3: Integration recognised

In the late 70ies the areas DFM and DFA are evolving, Boothroyd & Dewhurst [15], Huang [16], Andreasen [17], parallel with the emergence of integrated (concurrent, simultaneous) product development, Andreasen & Hein [20], Ulrich & Eppinger [33], Ehrlenspiel [14]. The DFM methodology is documented in books [18] on principles, companies develop their own internal guidelines, and – much later – lessons learned books, Kennedy [19], where the experienced results of design/manufacturing cooperation and the launched product are articulating what to do next time and what not to do again.

The organisation of DFM is normally teamwork, even if many companies actually have no staff members in the production area trained for participation in new product development. The procedural support is as mentioned typically integrated product development with a build in simultaneity of design and production oriented activities. Fig. 3 shows a characteristic integrated model of the design activity. However the integration and scope of DFM activities was sparse. Actually the synthesis of the production system and its gradual concretisation was not started earlier than “normal” and the production considerations made by the team was not seen as real, because the production specifications/drawings was not finished.

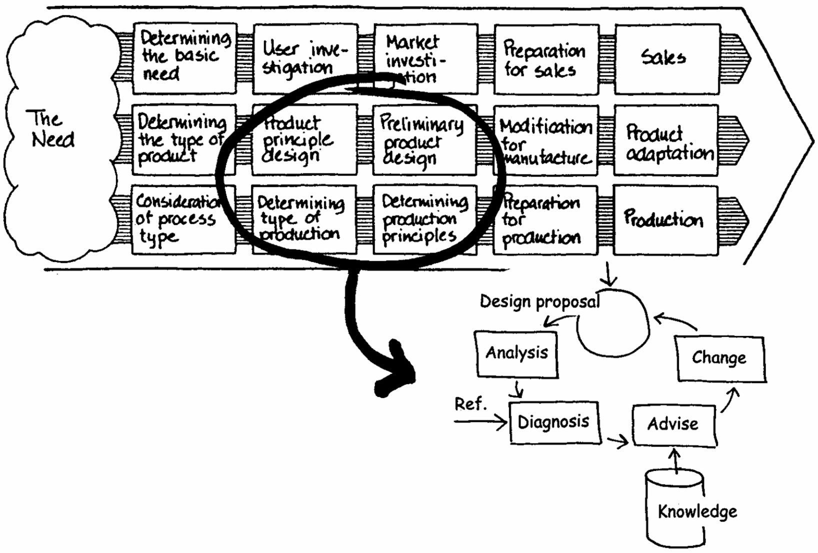

Fig. 3: A model of integrated product development, Andreasen & Hein [20] showing simultaneity of product- and production activities. DFM tools are used to add to the synthesis of the product in a corrective loop

Step 4: Computer integration

Roughly seen the development of integrated product development in Europe followed a strategic and business-oriented philosophy, while the area in USA took its out-spring in computer-based integration. The idea was that CAD models of the design in an unbroken flow of data should be fitted to production and transferred as the production basis.

Many approaches have been followed for bringing DFM methodology, knowledge and best practice into a computer system. The well-known and widely spread Boothroyd/Dewhurst [15] software tool is a knowledge based system, which follows a corrective cycle of diagnosis, advising and scoring of the DFM effort put into a solution. High expectations were related to feature-based approaches for linking characteristic form elements of the components to appropriate processes, tooling and production procedures. Those efforts are not successful, but they are not yet finalised or given up.

As pointed out by Meerkamm & Bauer [21], many tools for support of DFM become islands because the software operates in its own models of the design. Another central point is how to link the DFM principles and advices to the actual task the designer is working on. One approach is to make a diagnosis based upon automatic analysis of the design and following up with advice, mfk, Meerkamm, Storath & Rösch [22]. Another approach is to make „life-cycle consequences" visual and knowledge supported, i.e. to derive from the actual CAD-model and dialogue with the designer what is relevant life cycle modelling and advisers, Borg [23]. Yet another approach is to guide the designer through a sequence of detailed design steps, where each of the steps of synthesis is followed by inspection questions and advises, van Vliet [24]. The driving force behind computer integration is of course to harvest the high potential for reduction of cost and lead-time related to computer based work.

The balance today, as articulated by Vielhaber et al [25], is that we are facing a "paradigm shift in design philosophy" as shown in Fig. 4: CAD systems has forced us to apply a part-orientation of design and a component/process type of DFMA, which we today gradually is repairing with a so-called assembly-oriented design approach. Here assembly shall first of all be seen as the product structure (Baustruktur). One might say, that we has always known that a structural approach shall proceed a parts oriented one, because DFM reasoning on structural level has much more effect than the part oriented one, so the shift is more a shift to more appropriate tools than philosophy.

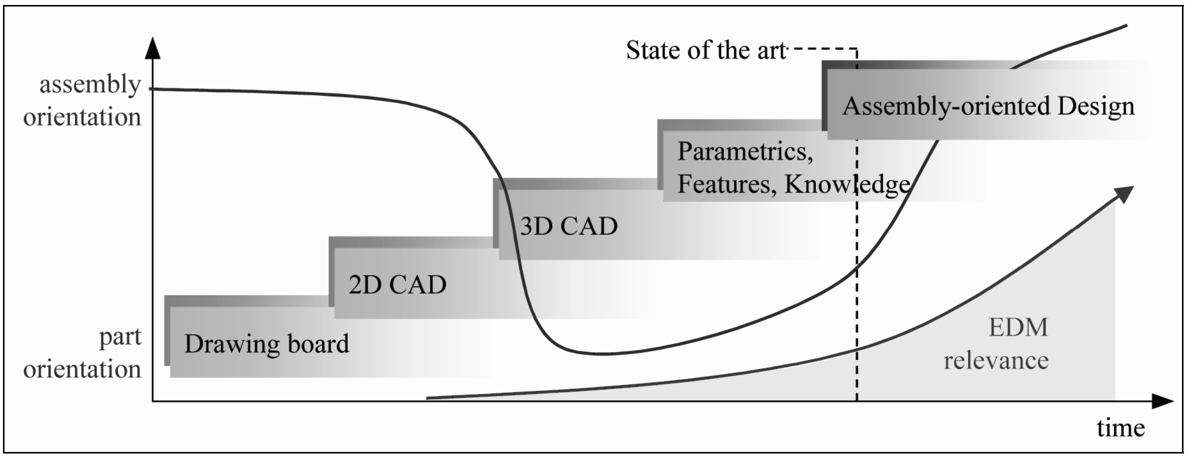

Fig. 4: Paradigm shifts in design philosophy, Vielhaber et al. [25].

5 The DFX Symposia

As said in the introduction we see a stagnating interest in the DFX-area at international conferences. At the ICED conferences the number of different DFX-topics grew until mid 90ies, but the manufacturing area has nearly vanished, see Fig. 5, Andreasen [26].

Design for X	81	83	85	87	89	91	93	95	97	99	01
Manufacture, cost	3	3	10	9	6	21	24	32	20	11	5
Quality, Reliability Maintenance	1	8	7	2	6	13	20	15	16	8	11
Environment, ecology						2	14	15	19	16	20
Others				2		3	11	4	4	5	6
Total	4	11	17	16	12	39	69	66	59	40	42
Relative to total number of papers%	4	9	15	13	12	16	26	19	16	10	13
Total number of pages	86	115	114	123	97	235	267	347	361	390	324

Fig. 5: Analysis of ICED conference topics, showing the growth and declining interest in DFM and DFX areas, Andreasen [26].

A similar analysis of the contributions to NordDesign (a biannual conference) from 1996 to 2004 shows a rather stable, but low contribution of DFX-papers (4 out of 40). The DFX-symposia shows the development illustrated in Fig. 6.

Here we see the following characteristics traits:

- Papers on DFM and manufacturing technologies are relatively sparse, as if everything was already told.

- Theory contributions on DFX, conceptual design, and design methodology, are supporting the DFM-area: The symposia brought contributions to Theory of Technical Systems, multi-DFX, DFX theory, design language and product modelling.

- Design for Manufacture efforts may be measured in cost, quality, and time, but also through environmental effects. The symposia shows little focus upon cost and we found only one paper on quality, while the generally growing global interest for ecology and environment is mirrored in the DFEn papers and later the papers on product-life aspects and product/service-systems.

- Design for Manufacture is also found in the many (14%) papers related to CAD, workbench-approaches and software based tools and in the papers on utilising management of knowledge, information and data for DFM-support. The hosting chair's work on the mfk workbench system was documented in a high number of papers, but also other contributions relate to the effort to add higher functionality to computer support by the help of product modelling and knowledge management, and new theories on characteristics and properties.

- Tolerancing is a central topic in several institutes participating in the symposia, and industrial needs have supported the high focus we see in the number of papers. 11% of the papers treat tolerancing.

- Design for Manufacture, like engineering design, shall be seen in the light of product development, especially the efforts here for integration, for taking the whole product life cycle in account, and for managing multi-product development, as we see it in modularisation and Baukasten approaches. This is mirrored in an 8%-part of the papers treating product development.

- The interests of the institutes joining the symposia are also mirrored in the papers on mechatronics (8%), a topic that only indirectly relates to DFM.

	← Egglofstein →					← Schnaittach →						← Neukirchen →						
	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	Sum
DFM(A)	1	4	5	3		1		1	1		1	3	1	1			2	24
Manufacturing technology	3	1	1		2	1		1	1	1					1	2	2	16
DFX-theory	3					1	1	1			1			1		1	1	10
Cost	1	2	1					1	1						2			8
CAD, workbench, SW	3	4	4	2	5	1	7	3	2	3	2	1	5					42
Tolerances			3		2	2	4	6	4	2	3	1	2	2	1		3	35
Conceptual design			1		1				1	1			1	1	1			7
Modularisation, Baukasten			1	1	1	4	1	1	3		3	2		2	3		1	23
Design Methodology					2			2	4	5	4	1	3	3	1	2	2	29
Design for environment					2	1			3	3				2	1			12
K/I/D managing				1	2	2	2		3		3	1	2	3	1	1		21
Product Development						3						1	2	1	6	5	8	26
Mechatronics								1	2	1	4	8	4	2		2		24
Product life, PSS								1				1	2			2	2	8
Miscellaneous				1		1	2	1	1	2	2	2	5			1	2	20
Sum	11	11	16	8	17	17	17	19	26	18	23	21	27	18	17	16	23	305

Fig. 6: The topics and papers of the DFX-symposia 1990-2006 arranged after appearance.

Basic approaches

If we balance the development sketched in section 4 and the contributions from the symposia summed up above, we see the following situation related to DFM:

- The core of DFM is still design principles, but specialisation forces companies to derive their own guidelines and “lessons learned”-books.

- The development related to computer support has lead to good attempts to let the computer reason about manufacturability or to let the computer choose more or less automatically good pair of solutions: element form and manufacturing processes.

- Many projects have attempted to create approaches, where the designer’s problem shall be met by recognised good solutions. These efforts seem not yet successful.

- The DFM-activities in industry are still only “single synthesis activities”, i.e. the production related considerations in DFM are not seen as early production synthesis steps.

These generalisations we believe are valid for the most companies except big, mass-producing companies, where the competitive force and the volume allow a very detailed, specific parallel development of products and production.

6 DFM today: A new situation

As pointed out in the introduction, DFM-oriented activities are rather invisible in the research world, in publications and seemingly not on industrial companies agendas for product development enhancement.

In the past we have seen the paradox that most companies are very keen on product costs, but show low interest in DFM, in spite of very convincing results reported from DFM-focused industrial projects. According to Boothroyd et al [15] the results from 43 published case studies where DFMA was used showed:

- An average part count reduction of 51% (based on 43 cases)
- An average reduction in assembly time of 61% (based on 31 cases)
- An average reduction in assembly cost of 41% (based on 18 cases)
- An average reduction in product cost of 37% (based on 12 cases)

Our explanation to the low interest was that DFM falls between two chairs: The product development manager’s chair and the production manager’s chair. The first one is not measured on his manufacturing costs efforts, the second one is not allowed to bring DFM into the design organisation.

Today we focus a new situation, which we will call:

Step 5: Mass-customisation and multi product development

Highly competitive markets, fast technology development, extreme cost competition and demands for quick reaction time, together with demands for customer fitted products, has led to new patterns of production, mass-customisation, and for product development. Central concepts are modularisation and platform thinking, Harlou [27], Andreasen et al [28]. We will take a closer look upon these topics relation to DFM.

When a product concept or an existing product is given a modular structure, a re-design activity is going on:

- based upon functional reasoning and analysis of expected variants a functional structure may be worked out.
- the functionality of each potential module is determined.
- the components belonging to the module are identified.
- and the design is altered in such a way that interfaces becomes feasible and can be standardized across the necessary module variants.

Modularisation has positive effects, if the new modular architecture can be used for rationalisation, for instance:

- fitted to suppliers, delivering assembly ready modules.
- fitted to manufacture for
    - high utilisation of given productive equipment.
    - late definition of product identity, rising volume in production seria.
- allowing repair by replacing modules.
- allowing upgrading by adding new modules.
- leading to a product structure, where future development can be focused upon few, competitive modules.

Each of these focuses on module drivers, Erixon [30], force the designer to DFX-operations, for instance to re-design modules so that they are fitted to and optimal for the supplier's production system, based upon DFM.

The manufacturing area is of course heavily influenced by the modularisation efforts. The space of variety of each module and the number of modules determine the complexity of operation, and the degree of re-use, pre-use and fitting the modules to the production system may lead to high commonality. Again we see here the DFM-area as a tool for rationalisation.

Fig. 7 shows an approach to visualisation of the product variation structure and its relation to the consequences in manufacture [29]. The method is based on a paper based jig saw puzzle depicting the product structure and the different manufacturing processes involved in the production of the products. In Fig. 7 the products are solenoid valves. The puzzle is used as a tool to generate visualisation of both product and production concepts. Design engineers are present along with production engineers during the generation and discussion of concepts ensuring a concurrency in the design decisions and the choice of manufacturing processes along with the layout of the factory in general. A key issue when working with the tool is to ensure a good balance between the structure of the products and the ability to build a highly versatile production set-up that will allow for a wide variety of products to be produced without long change over times. By this proactive approach of mapping the variation possibilities the design and production areas are given high degree of preparation, allowing quick, controlled and foreseen responses to requests, Erixon [30].

A modular product assortment may be defined in a product model [31,38] in such a way that configuration can be performed, i.e. the designer, sales agent or customer may compose the individual product for certain specifications. This means that the design activity takes nearly no time, and the chosen individual product may be ordered for production and/or assembled from the shelves.

This decoupling of design and production of course puts demand upon a careful activity of production oriented design and checking, so that all expected variants are producible. Here again we find the demand for DFM and its utilisation.

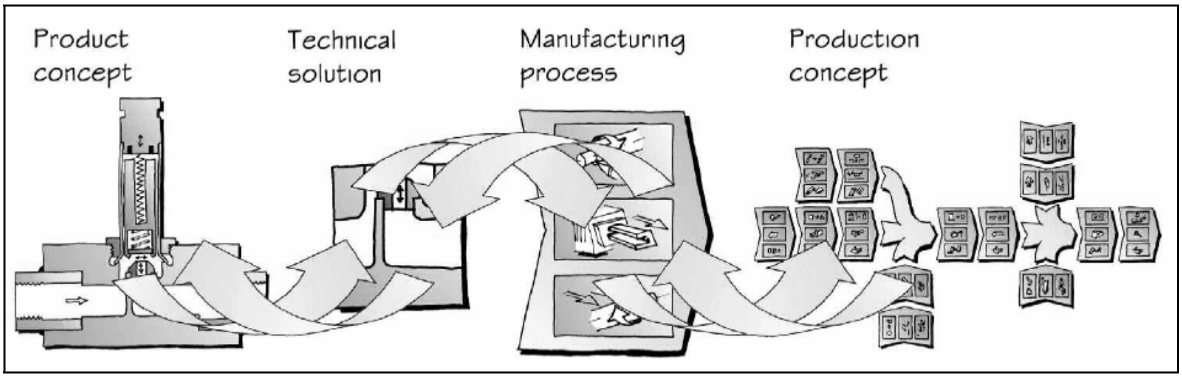

Fig. 7: The tool is used to model product and production concepts concurrently by both design and production engineers [29].

In our paper “Multi product development: New models and concepts” from the 15. Symposium we introduced a platform as a company’s efforts to align and utilise its assets. We showed how a platform could be seen as an alignment of architectures, but also as an articulation and enhancement of each area in question, for instance the product portfolio and the manufacturing system. Platform thinking means to master two time axes in new product development, namely the one following an actual project, and one crossing all projects in past and future to get control on the way each area shall operate and be aligned in other areas.

Fig. 8 shows the articulation and alignment efforts at LEGO for rationalisation and standardisation of injection moulding tools and articulation of the product-oriented efforts for creating many new designs with quick dealing and short market life. This alignment mirrors new conditions for LEGO business, and of course the alignment is based on detailed DFM-consideration, balancing the respecting of new designers and tooling costs, [32].

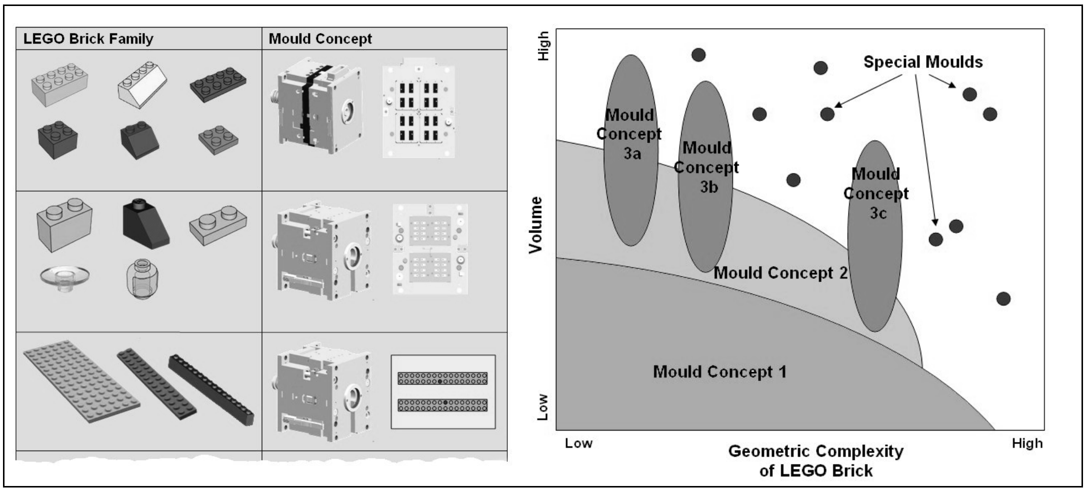

Fig. 8: LEGO is matching element families and mould concepts for controlling tool variation, commonality and agility in production. To the right LEGO’s definition of mould classes. [Ole Fiil-Nielsen]

Altogether we see that the multi-product development situations force companies to

- carefully plan variety and commonality of the products.
- to identify and control the consequences of the raised complexity in all company operations.

- to identify and enhance the areas, where the product architecture might support the rationalisation efforts, by poor alignment.

- to utilise the high preparation degree and the de-coupling of design and production for dynamic behaviour on the market place.

But these things are not new dreams and a consequence of the multi product development only, but elements of new product development which would be beneficial in any company in any situation. So it is our challenge to make this high degree of preparation and alignment a part of design, also in small and medium industries.

7 What happened to DFM?

The use of and the importance of DFM seems to be a matter of several factors:

- The awareness and insight about DFM methodology in industry. It is our feeling that company managers do not put sufficient pressure on cost reduction claims.

- The disturbing fact that even enhanced CAD-systems do not really support DFM and remove the focus away from structural considerations, - and therefore DFM is left out.

- The changed pattern of dynamics and competition on the market place, which point to extra DFM-efforts, but often, is substituted by outsourcing.

- The changed pattern of multi-product development, modularisation and configuration, which totally renew the question of lead time and reaction time, and which lead to a very articulated, proactive DFM-effort.

In this field we read a need and a challenge for reformulating the DFM area for proper proactive use, for modularisation and platform efforts, and for such an operationalisation that it become recognised as “must”-tool in industry. In this way DFM may help to fit modularisation and platform thinking to companies, which are substantially smaller than those who are today celebrating platform thinking, so that they can harvest the effects of proactive, aligned approaches.

The DFX-Symposia is a living, important arena for development of the DFX area. Many experimental, explorative, innovative papers have been presented at the symposia as a first try: “What do you think about this?”

8 References

[1] Andreasen, M.M., Mortensen, N.H.: Basic thinking patterns and working methods for multiple DFX. In: H. Meerkamm (edit): Proceedings of 8. Symposium, Fertigungsgerechtes Konstruieren, Schnaittach 1997. Lehrstuhl für Konstruktionstechnik, TU Erlangen-Nürnberg 1997.

[2] Andreasen, M.M.: The contributions of design research to industry – reflections on 20 years of ICED Conferences pp. 3-10 in S. Cully et al (edit): Design Research-Theories, Methodologies, and Product-Modelling. Proceedings of ICED 01, IMechE, London 2001.

[3] Cantamessa, M.: Design Research in perspective, - a meta-research on ICED 97 and ICED 99. In: S. Culley et al (edit): Design Research-Theories, Methodologies, and Product modelling. Proceedings of ICED 01, IMechE, London 2001.

[4] Olesen, J.: Concurrent Development in Manufacturing. PhD-thesis,Technical University of Denmark, Lyngby, Denmark. 1992. ISBN 87-89867-12-2.

[5] Kimura, F., Suzuki, H.: Design of Right Quality Products for Total Life Cycle Support. In Züst et al (edit): Proceedings of 3rd Int. seminar on Life Cycle Engineering, Verlag Industrielle Organisation, Zürich, 1996.

[6] Andreasen, M.M. Kähler, S. and Lund, T.: Design for Assembly, 2nd edition. IFS publications/Springer Verlag, 1988.

[7] Hubka, V. Eder, E.: Theory of technical System. Springer Verlag, Berlin 1988. ISBN 0-387-17451-6.

[8] Olesen, J. et al: Design for Environment (in Danish). Miljø- og Energiministeriet, Miljøstyrelsen, Denmark, 1997. ISBN 87-7810-435-1.

[9] Mørup, M.: Design for Quality. Diss. The Technical University of Denmark, Lyngby, 1993. ISBN 87-90130-00-6.

[10] McAloone, T.: Industrial Application of Environmentally Conscious Design. Professional Engineering Publishing, Bury St. Edmunds, 2000.

[11] Fabricius, F.: Design for Manufacture – DFM. EUREKA Secretariat, Brussels, 1994.

[12] Pahl, G. and Beitz, W.: Engineering Design: A Systematic Approach. 2nd edition, Springer Verlag, Berlin, 1996.

[13] Matousek, R.: Konstruktionslehre des allgemeinen Maschinenbaues. Berlin, Springer Verlag, 1957.

[14] Ehrlenspiel, K.: Integrierte Produktentwicklung, 2. Auflage. Hanser, München, 2003.

[15] Boothroyd G. and Dewhurst, P.: Design for Assembly Handbook, Boothroyd Dewhurst Inc. 1983.

[16] Huang, G.Q.: Design for X. Chapman and Hall, 1996.

[17] Bauer, S.: Design for X - Ansätze zur Definition und strukturierung. In: Meerkamm, H. (edit): Proceedings of 14. Symposium “Design for X”, Neukirchen 2003, Lehrstuhl für Konstruktionstechnik, TU Erlangen-Nürnberg, 2004

[18] Andreasen, M.M & Ahm, T.: Flexible Automated Assembly, IFS Ltd. UK, 1988.

[19] Kennedy, M.N.: Product Development for the Lean Enterprise: Why Toyota’s System Is Four Times More Productive and How You Can Implement It. Oaklea Press, April 2003. ISBN 1892538091.

[20] Andreasen, M.M. &Hein, L.: Integrated Product Development. IFS (Publications), Springer Verlag, Berlin, New York, 1987. ISBN 0-387-16679-3.

[21] Meerkamm, H. & Koch, M.: Design for X. Chapter 12 in: J. Clarkson & C. Eckard (edit): Design Process improvement – a review of current practice. Springer, London, 2005.

[22] Meerkamm, H. Starath, E. & Rösch: Demonstration of mfk at 6. Symposium ”Fertigungsgerichtes konstruieren”, 1995.

[23] Borg, J.C.: Design Synthesis for Multi-X – A Life-cycle Consequence Knowledge Approach. Thesis, University of Strathclyde, 1999.

[24] van Vliet, J.W.: Design for Manufacturing – development and application of a process-based design support methodology. Theses TU Delft, 2001. ISBN 90-370-0191-2.

[25] Vielhaber, M Burr, H. Deubel, T. Weber, C., Haaris, S.: Assembly-oriented design in automotive engineering. In: Marjanovic, D (edit): Proceedings of International Design Conference DESIGN 2004, pp.539-546, University of Zagreb, 2004.

[26] Andreasen, M.M.: The contributions of design research to industry – reflections on 20 years of ICED Conferences pp. 3-10 in S. Cully et al (edit): Design Research- Theories, methodologies, and Product-Modelling. Proceedings of ICED 01, IMechE, London 2001.

[27] Harlou, U. Mortensen, N.H. & Andreasen, M.M.: A product family master plan as basis for product modelling and engineering design. Proceedings from Fuglsø Workshop, Aalborg University, 2000.

[28] Andreasen, M.M. Mortensen, N.H. & Harlou, U.: Multi product development: New models and concepts. In: Meerkamm, H (edit): Proceedings of 15. symposium, Design for X, 2004. Lehrstuhl für Konstruktionstechnik, TU Erlangen-Nürnberg, 2004.

[29] Pedersen, R. Kvist, M Mortensen, N.H.: Method for Alignment of product and production concepts, International Conference on engineering design, ICED 2005, Melbourne Australia, August 2005.

[30] Erixon, G.: Modular Function Deployment – A Method for Product Modularisation. Doctoral Thesis, KTH Stockholm, 1998.

[31] Mortensen, N.H.: Design Modelling in a Designer's Workbench – Contribution to a Design Language. PhD thesis, Technical University of Denmark, 1999.

[32] Fiil-Nielsen, O.: K&P internal working document based on case studies at LEGO Company A/S

[33] Ulrich, K.T & Eppinger S.D.: Product Design and development. MCGraw-Hill, Boston, 2000.

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