Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 21 (2014) 81 – 86

www.elsevier.com/locate/procedia

24th CIRP Design Conference

Forward Variance Planning and Modeling of multi-variant Products

Paul Christoph Gembarski*, Roland Lachmayer

Institut für Produktentwicklung und Gerätebau, Leibniz Universität Hannover, Welfengarten 1A, 30167 Hannover

* Corresponding author. Tel.: +49-0511-762-5361; fax:+49-0511-762-4506.*E-mail address:* gembarski@ipeg.uni-hannover.de

Abstract

Planning multi-variant products in the early stage of the design process is still a challenge. In the present paper, a specification technique is introduced in order to define multi-variant products using degrees of freedom of shape attributes (in the following shape-DoFs) within the product structure. Our goal is to plan variety actively at the beginning of product development and not to describe variety by change of parameter values of the product's components as introduced in variant trees. Shape-DoFs are classified in the fields of shape attributes (dimension, position, shape as well as their combinations) on the one hand and mandatory or optional components on the other hand. Set up on this taxonomy graphical symbols are introduced to be used in product modeling. As application example, a welded pipe rack based upon the assembly structure modeling the product structure in this way is visualized in the first step. The second step is to translate the shape-DoFs into design parameters and identify relationships between them. The result is a parameter plan, as well as a configuration concept. Both can be seen as basis for CAD-modeling the product as design template which is the third step. In case of our example, Autodesk Inventor (without the ETO-Environment) is used to create the CAD-data. Discussing the effects of the proposed method, it will be shown that different shape-DoFs may cause various impacts in the whole product development process. Regarding these effects, scenarios can be performed in order to identify the cost and resource optimal variation possibilities of the product. In addition, it will be shown that different kinds of modularity according to PINE (e.g. cut-to-fit-modularity) can be predefined in the product model by using shape-DoFs

Selection and peer-review under responsibility of the International Scientific Committee of “24th CIRP Design Conference” in the person of the Conference Chairs Giovanni Moroni and Tullio Tolio

Keywords: specification technique; product configuration; complexity management; product structure; shape-DoFs; product customization

1. Introduction

Market development in many industrial sectors shows tendencies to more customer specific and technically more complicated products. It is generally accepted that the customer's desired and perceived diversity as well as the desired individuality of products should be dealt with a minimum of organizational efforts.

In the present paper, a process model is introduced in order to define multi-variant products. Therefore we extend a product's assembly structure using degrees of freedom of shape attributes (in the following shape-DoFs) in order to define distinct variation possibilities. Usually, both product structure and the component's shape are considered individually. For certain products implementing both has advantages for modeling [1].

1.1. Motivation

Planning multi-variant products in the early stage of the design process is still a challenge. Focusing on the product structure, the use of modular product structures has proven favorable regarding design efforts for customizable products [2]. There, diversity is realized by using optional components or exchanging separate modules due to either functional or design aspects.

Products with a modular structure are also suitable for processing in a configuration system. Within such a design configurator geometry is extended not only by BOM-attributes and parameters. Also constraints and design rules may be implemented. In order to set up an user dialog a

Selection and peer-review under responsibility of the International Scientific Committee of “24th CIRP Design Conference” in the person of the Conference Chairs Giovanni Moroni and Tullio Tolio
doi:10.1016/j.procir.2014.03.161

graphical user interface for the configuration task commonly is obtainable.

A lot of CAD-configurators is available. The basic setup as well as the general structure of the configuration tasks is well understood [3]. But there is a lack of methodologies investigating in which way a configurable product has to be planned and set up in such a system.

The approach presented in the present paper aims on this gap. According to our method a component's degrees of freedom (especially shape-DoFs) are intentionally used in order to plan and benchmark diversity regarding technical and economical aspects. In the second step these shape-DoFs have to be translated into design variables and model parameters. In particular relationships between those parameters have to be considered as well as design and configuration rules.

Based upon this a CAD-system specific modeling can be done. In our application example Autodesk Inventor is used to set up a basic CAD-configurator.

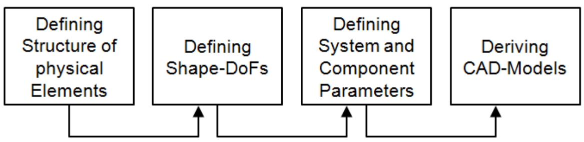


Fig. 1. Forward Variance Planning and Modeling

This method is introduced as Forward Variance Planning and Modeling (Fig. 1).

1.2. Structure of the Paper

In the following chapter 2 previous approaches of modeling product structures of multi-variant products are presented. Chapter 3 then shows our method using shape DoFs.

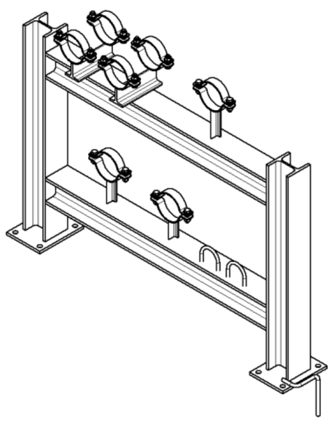


Fig. 2. Application Example - Welded Pipe Rack

An application example (a welded pipe rack, Fig. 2) then visualizes the concept. In chapter 4 the degrees of freedom are transformed into parameters and configuration rules. The next to last chapter 5 sums up the implementation into the CAD environment. Closing the paper chapter 6 contains a brief outline and drafts prospect questions.

2. Structuring multi-variant Products

Product structuring can be done in different ways. Generally accepted is the representation using either assembly structures (the structure of physical components), structures of functionality, or product architectures [4].

The assembly structure resembles the manufacturing and assembly sequence, whereas the structure of functionality describes the relation of main- and sub-functions. Both views on the product structure are mapped within the product architecture which translates functions into physical components. Regarding the assembly structure, it is represented by either a hierarchical component tree or graphs. Diversity therein is represented as alternative or optional components.

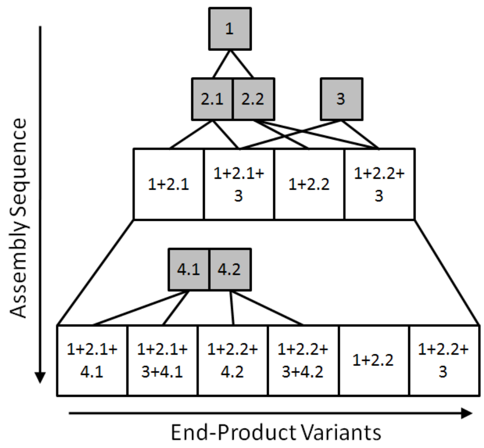


Fig. 3. Variant Tree

In order to describe variance within product structures, variant trees where suggested [5]. There a component's different occurrences are placed side-by-side in a hierarchical tree, which represents the assembly sequence. So the last row corresponds to the maximum count of all product variants (Fig. 3). Using restrictions expressed by configuration rules or interdictions of application, the optimal amount of product variants can be worked out. Therefore all occurrences of the product and its components have to be specified before.

A different approach is the use of degrees of freedom (DoFs) in product structures which is discussed recently. In general, a component's DoFs can be understood as parameters (either physical, geometrical or numerical) that may vary independently.

In one representation so called cardinalities were implemented which have to be understood as variables for distinct component occurrences [6, 7]. So, the product model can be written as generic kind-of-model or class diagram known from programming and database design.

Advancing is another method which distinguishes different areas in the product structure. Therefore fixed and scalable arrays, optional and mandatory alternatives as well as predefined and general spaces have to be differentiated in order to adapt a product to new market conditions or functional requirements [8].

3. Degrees of Freedom of Shape Attributes (shape-DoFs)

Picking up this approach we define general degrees of freedom using shape and body attributes [9]. This leads to variable size, position and shape and their according DoFs. They are extended by a layout DoF which means that a sub-function is planned but yet not designed (this will e.g. be done when this sub-function is explicitly demanded by a customer).

In order to indicate a selection between different component occurrences also an appropriate DoF is introduced. Additionally mandatory and optional components have to be differentiated within the product structure [10].

3.1. Symbols

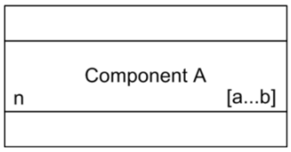
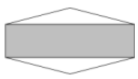
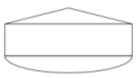


Fig. 4. Symbol

For modeling multi-variant products, graphical symbols are introduced. These are built up in three elements (Fig. 4). The upper part is the usage marker. It indicates whether the component is mandatory (rectangular) or optional (triangular). The mid part contains the information field with the component identifier (name or drawing number). It is completed with the quantity *n* on the lower left and a value range *[a...b]* on the lower right (e.g. when a position has to be in between 100 and 200 mm). The bottom part is the DoF marker.

An overview of the resulting model elements is given in Table 1.

Table 1. Shape-DoFs.

Degree of Freedom	Mandatory Component	Optional Component
no DoF		
selection / choice		
position		
size		
shape		
layout	n.a.	

In addition the combination of shape-DoFs is allowed so a component can have e.g. both a position and a size DoF.

3.2. Application example

To visualize the concept, single sub-assemblies of the pipe rack are modeled in the following.

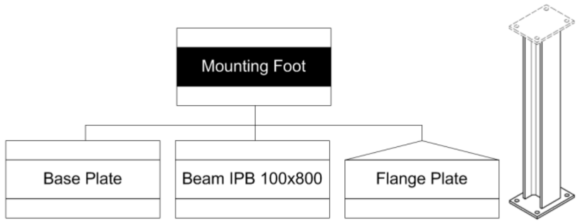


Fig. 5. Base Symbols

Base symbols are used for fully determined and fixed components which don't have any DoFs (no geometric variation possibilities). Improving readability, the top node should be labeled with another color (see example above, *Mounting Foot*). The usage marker identifies the components *Base Plate* and *Beam IPB 100x800* as mandatory, *the Flange Plate* is optional (Fig. 5).

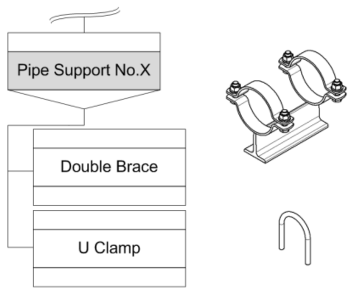


Fig. 6. Selection Symbols

Selections within the product structure are represented by a symmetric triangle in the DoF marker and a grey information field (Fig. 6). These nodes have to be understood as placeholders in the product structure. In the example above, the pipe support *No. X* could be built either as *Double Brace* or as *U Clamp*.

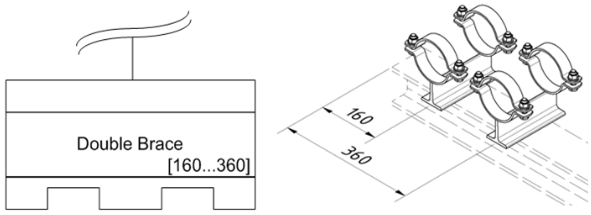


Fig. 7. Position DoF

For example, variable positioning of a component is indicated by a cut-out rectangle the DoF marker (Fig. 7). In the case above, the value range expresses that the double brace has to be mounted in between 160 and 360 mm measured form the base line. The representation can be extended to all three space coordinates (variable position in X, Y and Z).

The modeling concept is able to represent PINE's cut-to-fit modularity like in the example below [11]:

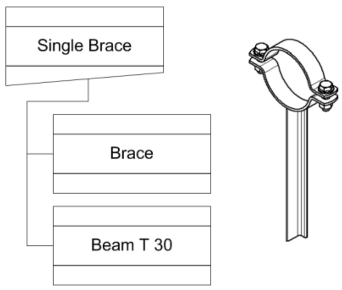


Fig. 8. PINE's cut-to-fit modularity modeled through shape-DoFs

The *Single Brace* above is pre-manufactured from a clamp and a beam in a distinct length. When used in an assembly, this brace is taken and then cut-to-fit. So the size DoF is used for the sub assembly *Single Brace* but not in its parts (Fig. 8).

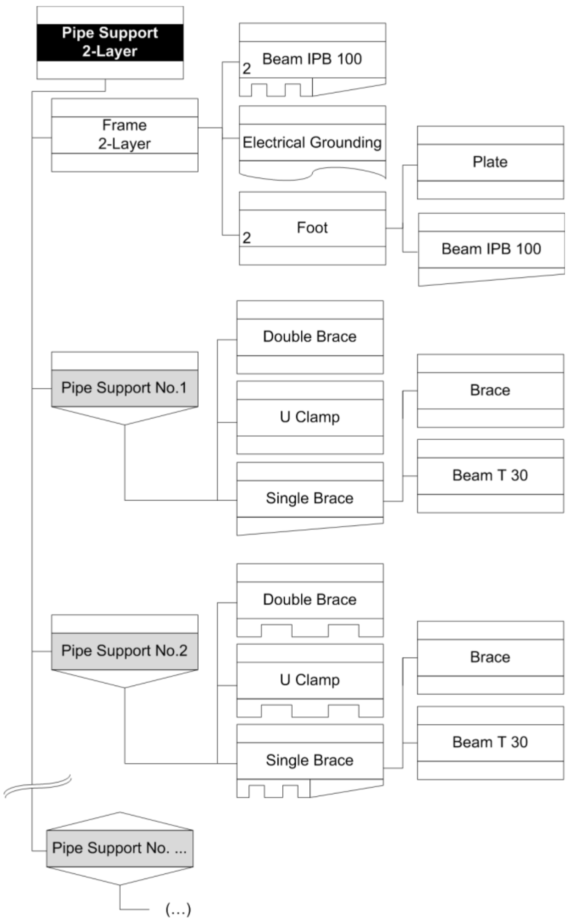


Fig. 9. Pipe Rack modeled with Shape-DoFs

Using the simplification that the diameter of the pipe supports is not considered which would result in selections for each support the above product model represents the application example (Fig. 9).

4. Defining Parameters and Configuration Rules

For defining the parameters, two steps are necessary. First, the single shape-DoFs have to be translated into design parameters. Secondly, the basic configuration parameters for the complete product have to be determined. Afterwards both can be linked using mathematical relationships or configuration rules.

For easier understanding the application example is reduced to a rack with only two supports.

4.1. Parameters resulting of shape-DoFs

Regarding the frame, shape-DoFs for length and position of the cross beams have been defined (here only the z-position is relevant) as well as length-DoFs for the beam in the foot assembly.

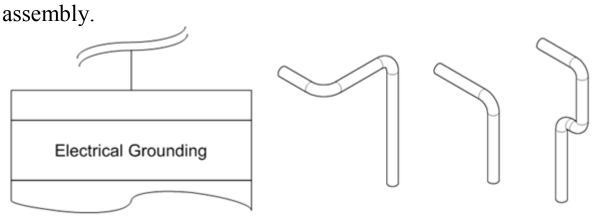


Fig. 10. Shape DoF of Electrical Grounding

The electrical grounding has a shape DoF, so it cannot be foreseen in which way it will be bent due to the later assembly situation (Fig. 10). Nevertheless, an interface parameter is defined (wire diameter).

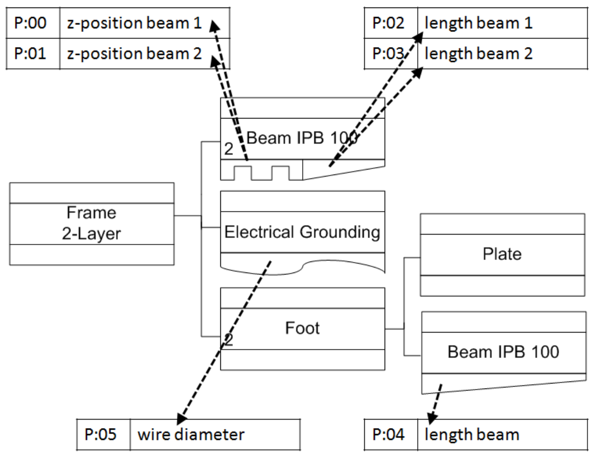


Fig. 11. Resulting Parameters in the Frame

The DoFs are translated into parameters which have to be used in a later CAD-models. Since these result in part parameters, the notation will be P:X with X as continuing index (Fig. 11).

The height above ground of the two cross beams there is described by the parameters P:00 and P:01, their length is expressed by P:02 and P:03. P:04 is the resulting length of the foot's beam, P:05 resembles the above interface parameter of the electrical grounding.

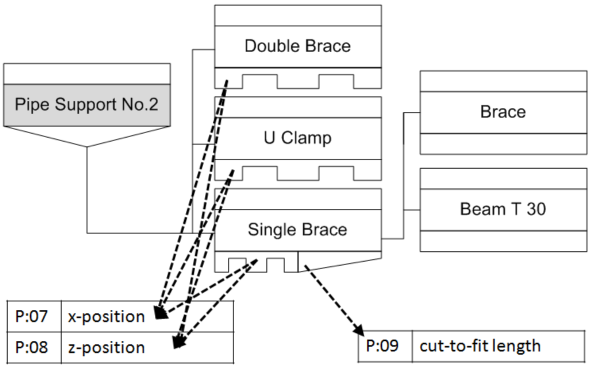


Fig. 12. Resulting Parameters in Pipe Support No.2

Since pipe support no.1 is kept in a fixed position in order to define the outline of the pipe rack it has only a length DoF for the single brace (which results in parameter P:06).

Pipe support no.2 is additionally equipped with a position DoF where as well z- as x-position is relevant (Fig. 12).

4.2. Configuration Parameters

In order to define a single pipe support in this case four parameters are needed. At first the position in x and z has to specified, secondly the pipe diameter (DN). At last the type of the support is chosen.

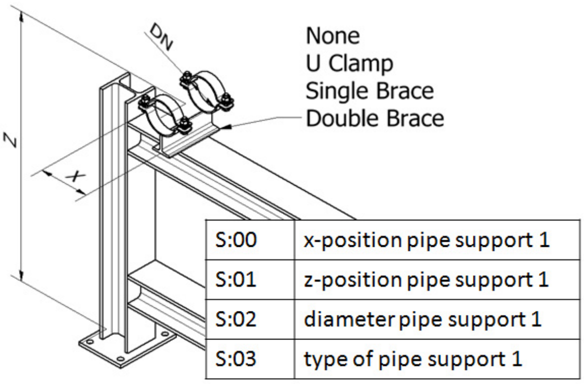


Fig. 13. System Parameters for a Single Pipe Support

Within a double layer pipe rack at least two supports have to be specified so that the position of the beams can be obtained. Since configuration parameters can be considered as system parameters the notation is S:X with X as continuing index (Fig. 13).

4.3. Linking Part and System Parameters

The parameters are listed in a table which contains the parameter name as well as its value, the unit and a comment.

The value is either a user input in case of system parameters or it is calculated by a equation or configuration rule.

name	value	unit	comment
S:00	140	mm	x-position pipe support 1
S:01	800	mm	z-position pipe support 1
S:02	100	mm	diameter pipe support 1
S:03	1	-	type of pipe support 1
S:04	200	mm	x-position pipe support 2
...			
P:01	=S:01 – height of used support	mm	z-position cross beam level 1
P:02	=...	mm	z-position cross beam level 2
P:03	=...	mm	length cross beam level 1
P:04	=P:03	mm	length cross beam level 2

Fig. 14. Parameter Table

There, both parameter types are allowed for processing, a part parameter can be related with a system parameter or with another part parameter (Fig. 14).

Also fixed model parameter can be used like the height of the used pipe support in order to calculate the z-position of the cross beam.

5. Implementation in the CAD-Environment

The parameter table according to Fig. 13 can directly be imported into Autodesk Inventor using the embedded excel spreadsheet.

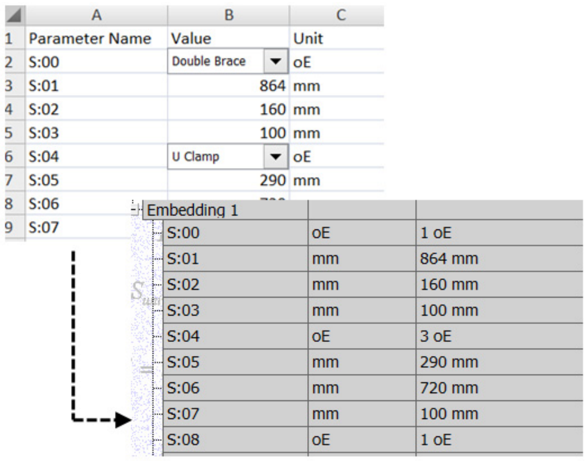


Fig. 15. Embedded Excel Spreadsheet

Regarding the configuration task excel is favorable for setting up the parameter table because controls like dropdown boxes are available as well as multiple arithmetic operations and evaluations like the IF-function (Fig. 15).

In the following a skeleton is set up in order to derive parameters and sketches into the single CAD-models.

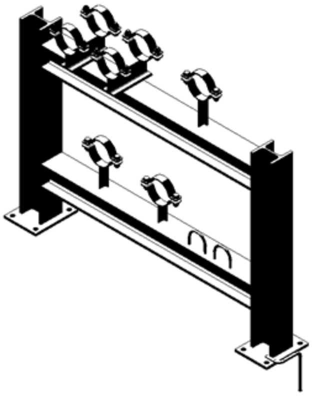


Fig. 16. Final Assembly

Based upon this the single parts are modeled and the assembly is built (Fig. 16).

6. Conclusion

In the present paper Forward Variance Planning and Modeling of multi-variant products was introduced in order to model a product's variability using shape-DoFs in the product structure. The goal is to actively plan variability in the early stages of product development. The defined DoFs then were translated into system and part parameters which can directly be used for setting up a basic CAD-configurator.

The process model still has limitations and simplifications that will be released in the next steps.

Until now we have used three shape and body attributes (position, size, shape) for modeling. It has to be examined if other attributes lead to other DoFs necessary for modeling. There, it has to be looked after the complexity of the modeling approach, too many DoFs will perhaps lead to challenges in modeling products in a simple way.

In the example a welded assembly on sub-assembly level was examined where part and component parameters were varied using the DoFs. On a lower level parts can be modeled as well, there parameters for single design elements or CAD-features can be addressed with shape-DoFs. On the other hand the higher modeling level will lead to whole products.

In addition it has to be proved that other types of products can be modeled as well, e.g., mechanical devices or mechatronical products. Furthermore more complicated products need to be modeled especially with a more complicated product architecture and interacting DoFs.

In the present example a simple parametric model could be used because of simple relationships between the single parameters. In future examples this has to be withdrawn and also physical parameters have to be implemented in order to e.g. translate forces into geometric dimensions.

Regarding the process model it has to be examined if the single steps have to be directional. For example steps one and three, planning the structure of physical elements and planning the parameters could be done top-down and steps two and four, defining shape-DoFs and deriving CAD-models could be done bottom-up.

With respect to other existing methods for modeling multi-variant products the presented approach integrates both component view and attribute view. Planning variety furthermore leads to rating different options of variety which may be done for example based upon an economic basis.

Regarding economic aspects we hypothesize that different shape-DoFs lead to different costs in manufacturing. If a size DoF can be realized through another cut length the position DoF within a welding assembly might require new or adapted jigs. Special attention has to be paid on the effects of the shape DoF. Recent manufacturing techniques like rapid prototyping and additive manufacturing offer new potentials there. So it has to be examined if cost scenarios can be deduced of product models set up with shape DoFs.

References

[1] Sedchaicharn, K., 2010. A computer-aided method for defining the product architecture with consideration of function and geometry. Dissertation, Karlsruhe

[2] Lindemann, U., Maurer, M., Braun, T., 2009. Structural Complexity Management. Springer, Berlin, ISBN 978-3540878889

[3] Lutz, C., 2011. Rechnergestütztes Konfigurieren und Auslegen individualisierter Produkte. Dissertation, Wien

[4] Marti, M., 2007. Complexity Management: Optimizing Product Architecture of Industrial Products. Deutscher Universitäts-Verlag, Wiesbaden

[5] Schuh, G., Schwenk, U., 2001. Produktkomplexität managen. Hanser, München, ISBN 978-3446187795

[6] Asikainen, T., Männistö, T., Soininen, T., 2004. Using a Configurator for Modelling and Configuring Software Product Lines Based on Feature Models. In Workshop on Software Variability Management for Product Derivation, Software Product Line Conference. Technical Report HUT-SoberIT-C6, Helsinki University of Technology, Espoo, Finland.

[7] Asikainen, T., Männistö, T., Soininen, T., 2007. Kumbang: A domain ontology for modelling variability in software product families. Advanced Engineering Informatics, volume 21, number 1, pp. 23-40. Elsevier Science

[8] Lindemann, U., Reichwald, R., Zäh, M.F., 2006. Individualisierte Produkte – Komplexität beherrschen in Entwicklung und Produktion. Springer, Berlin ISBN 978-3540255062

[9] Koller, R., 1998. Konstruktionslehre für den Maschinenbau - Grundlagen zur Neu- und Weiterentwicklung technischer Produkte. Springer, Berlin ISBN 978-3540630371

[10] Gembarski, P. C., Lachmayer, R., 2014. A Method for Specification of Multi-Variant Products using Degrees of Freedom of Shape Attributes in Product Structures. In Proceedings of the 7th World Conference on Mass Customization, Personolization and Co-Creation (MCPC 2014), Aalborg, Denmark, February 4th-7th, 2014, pp. 27-37

[11] Pine, B.J., 1992. Mass Customization: The New Frontier in Business Competition. Harvard Business School Press, ISBN 978-0875843728