The 2nd International Conference on Design Creativity (ICDC2012)
Glasgow, UK, 18th-20th September 2012

CREATIVE DESIGN OPPORTUNITIES INTO KNOWLEDGE BASED ENGINEERING PROCESS

J. Boxberger[1], M. Lebouteiller[2], D. Schlegeld[3], N. Lebaaln[3] and S. Gomes[3]

[1]Zurfluh-Feller, Autechau-Roide, France
[2]Faurecia industrie Bavans, France
[3]Université de technologie Belfort-Montbéliard, France

Abstract: High competition and low manufacturing costs in emerging countries, forces European firms to improve quality, cost and delivery. In this context, research and development departments have to look towards high production design methods and tools in order to stay competitive. The main goal of our research is to reduce routine design process and thereby increase time for creative design tasks, particularly, creative design in new concept creation, optimisation and validation, by integrating data management, information management, knowledge management, and decision-support methods and tools, such as PDM (product data management), PLM (product life management), KBE (Knowledge based engineering), etc. Our methodology deals with reduction of routine design activities by introducing automatic activities during project, product and process design tasks in order to generate time for creative design. A 3D model generated by KBE tools is able to make new concepts crossing different parameters together, then the new concepts are automaticaly checked by validation loops, including product validation and process validation. Our methodology is tested in a firm specialized in shutter components. By implementing this method in an industrial company, we can reduce routine design, improve the design robustness and also take the opportunity to try new concepts, materials, combinations and at the same time implement new knowledge for future concepts.

Keywords: *Creative design, Knowledge Based Engineering, Product life management, Product data management, Routine design*

1. Introduction

The current industrial context forces companies to develop new concepts at ever increasing speed. Quality, cost and lead time are the relevant indicators for firms (Miles, 1992), (Yeh, 1992). However, after having shifted manufacturing to low cost countries, to prevent the relocation of work dedicated to routine design, we must reduce the length of the non value-added tasks to free up time for innovative projects and new product. This paper contains several sections: in the introduction we relate our current research on reducing routine design time, especially design for X, knowledge capitalization, top down design etc... The second section deals with our methodology which aims to reduce routine design in favour of creative design. The main goals of our contribution will be explained in this part. The next section presents an actual applied case. In this section, we have applied our methodology to shutter plastic components. Today, in order to minimise loss of information, different departments in a firm work together around the product lifecycle (product lifecycle management: PLM) from the customers' needs, to the end of life (Stark, 2004) (CIMdata Incorporated, 2009). Different approaches called integrated design, parallel design or collaborative design have already been developed (Tichkiewitch, 1994) (Lu, 2007). These methods have allowed us to deal with the knowledge domain earlier in the design process. In this context, an approach, called Design for X (Baxter, 2008) design for manufacture, design for assembly, design for quality, design for recycling etc...) has been created in order to reduce product lifecycle and also increase engineering productivity by reducing non value-added tasks. A large number of paper have been written over the last forty years about product design (Hubka, 1988), (Hauschild, 2005), (Li, 2006). Two clusters have been recognized (Deneux, 2002): Routine design where the product is already known and the outcome is known and Initial design composed of innovative design or creative design. We invent a new product without any reference or experience. Routine design occupies a large place in firms. Creative design could be increased by reducing routine design and this could also release time for other tasks. Figure 1 shows time repartition between routine and creative design in most of firms and the impact of using application such as KBE (Skarka, 2007). Within the Design for X, design for manufacturing and design for assembly have been the most discussed topics in the last thirty years.

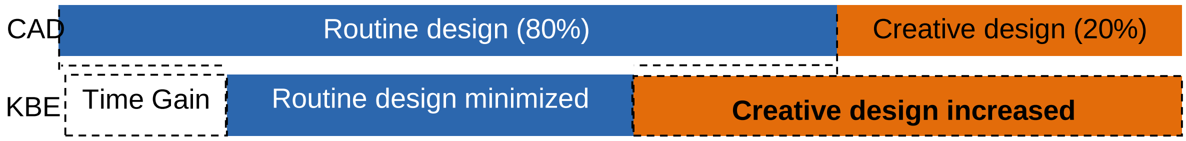


Figure 13 : KBE impact on main tasks in CAD during product development

The knowledge available in the manufacturing process has to be known by the designers in order to speed up product design and find the best quality product faster. Swift describes some standard rules about DFM (Swift, 2003). Using these rules as a base for KBE application, parametric models can be created and coupled with an optimization algorithm for problem resolution (Toussaint, 2011). Our modeling creation is articulated around the DFM method and decision support. A non-experienced user can lose time selecting the correct reference amongst a large number of references for the first time. In addition, he may choose the wrong reference or not the best one. Another problem is saving time and improving quality in creating a new product: when a new part needs to be created , a new tool needs to be adapted to this new case. It's also a great opportunity to test unknown geometries, unknown settings, unknown combinations. Because of the functional feature and structure of products, corresponding relationships exist, such as one to one, one to many, many to one and many to many. Similarly different functional features will lead to different structures and shapes of products (Hsu, 1998), (Xiao, 2010). Table 1, shows the principle of multi-configuration design with a non-exhaustive list. Creative concepts can be created, even if they are impossible or crazy. Sometimes paradoxical combinations will need TRIZ method (Cavallucci, 2001). The theory proposed by Hatchuel is based on the interdependence between concepts and knowledge (Hatchuel, 1996). Knowledge and rules must be shared for the new product in order to check if the new settings are compatible with a target (for example, the price, the material resistance, etc…). However, rules can change slightly because of new geometry or settings. Obtaining the optimum settings is often the result of tiresome trial and error corrections, during which time the various solutions are tested and modified. As a result, the settings are often non optimal and are just acceptable. Achieving the optimal design is time consuming and one of the highest material and manpower costs. However, in many processes and structural designs, in order to improve quality and reduce time, the combination of numerical simulation using the finite element method with numerical optimisation techniques cannot be avoided (Wei, 2009), (Lebaal, 2010), (Ou, 2012), (Naceur, 2008), (Oudjene, 2009). Our contribution will deal with a multi-objective optimization procedure, used to improve performance in injection moulding, coupled with automatic moulding tool design based on expert knowledge.

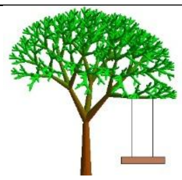
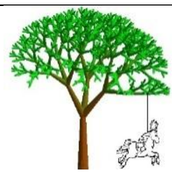
model	1	2	3
Shape			
Seat material	Wood	Plastic	Steel
Number of rope	1	2	3
Rope material	Natural	Elastic	Steel
Fixation	Noded	Bolted	Crimped
Rope diameter (mm)	[1-5[	[5-10[	[10-20[
Number of seats	1	2	3

Table 1. Different design configurations for a swing

Finally, we can suppose that lean manufacturing will also be applied to the project design field. Reducing non value-added tasks in this project domain improves productivity and quality of the product and the design process activities.

2. Methodology

The main goal of the following method is to allow creative design insertion in the project. On the other hand, routine design is present in all the domains: from the project domain, to the product domain; our contribution will also deal with the process domain. Obviously, all are linked together. The first project domain is relative to the whole methodology used in the firm: from the customer needs to the final product and marketing. In a project, many parts are often available in a large range of sizes within a family. If a new assembly is modified, e.g. new geometry or new size of one or several features, the user has to select a new component compatible with the new assembly, from within the same family. A standard method will design the new part using existing knowledge and past experience. Therefore, creative design can be developed inside the design phase. In order to avoid wasting time, the creation method is based on design for manufacturing method and on models lead by KBE. Additionally, the tool features automatic 3D model generation, including the part and the manufacturing tool together. The goal of the whole methodology described in Figure 14 is to allow new creative thinking, and new knowledge extraction from the new models created.

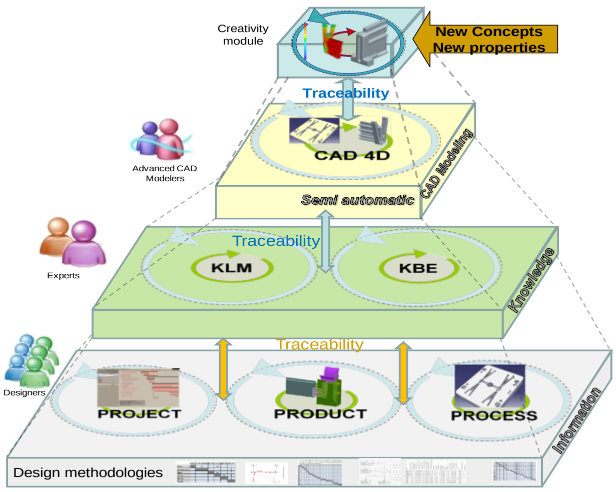


Figure 14. Pyramid Creation method

The creativity module is composed of finite element tool, optimization tool linked to the KBE application. First, the experts input the rules related to his domain (equations, interactions, manufacturing tool settings, etc…) into a PLM tool. This information collection leads to the creation of the KBE application. The creation of the KBE application depends on the particular case and on the manufacturing process. Our methodology path can be represented by a BPMN graph (Figure 15). It shows the methodology used and also the works currently tested and the results that we are expecting. Then two cases are possible when we apply new data into the KBE application: An existing reference is compatible with the tolerance range entered in the KBE model by the expert; therefore the user does not have to carry out research among a large number of references. No existing reference is compatible with our data. Hence, the application detects a miss match and will make calculate a vast range of possible combinations of parameters using a cross creative table. As a result, the new models created will use known combinations of parameters, but also, unknown combinations of parameters.

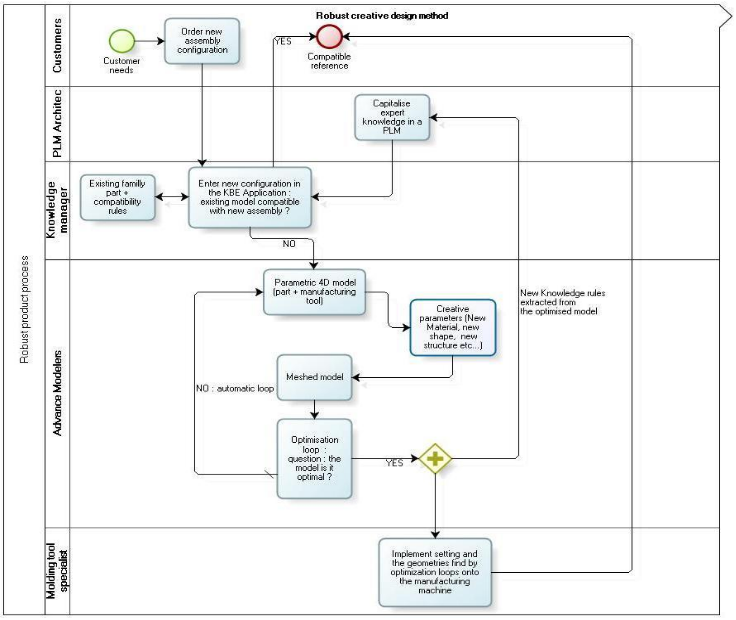


Figure 15. Lean manufacturing method applied to design processes for creative concepts creation

2.1 Creative Table

A table has been built in order to define further possibility for testing and optimizing in a optimization loop. The discovery table (Table 3) shows existing and absent solutions between 2 parameters chosen. This table can be used as reference to target existing solutions and non used solutions (a cross represent an existing design cases). As a result a larger table (Table 3) can be built. Using such a table allows several parameters to be combined and finds a vast number of new parts, even inconsistent parts, which will be tested in finite element software and calculation loops. As a result some valid creative components using new configurations of parameters can be found for the user. Then, by the connections established between the parametric model, the meshing tool and the optimization tool, loops can be performed, with the help of optimization algorithms. When the best product is found, a last loop is performed between the optimized model and the PLM tool. This last loop contains information and knowledge according to the value stream defined and optimized in the first loops. The knowledge can be dimensional (geometrical improvements that reduce the manufacturing time cycle), or the manufacturing settings. This methodology allows a knowledge loop between the models, the PLM tool and the expert to be created. This will lead to an increase of productivity and a knowledge record without any loss of information. The experts must validate the new knowledge implemented in the PLM knowledge base, but we can envisage experts not having to include this in the loop when the models are stabilized and reliable.

Material / Constant thickness (mm)	PP	PP55	ZAMAK	PA	POM
[0-1[		x			
[1-1.5[		x			
[1.5-2[		x		x	
[2-2.5[	x	x		x	
[2.5-3[	x	x		x	

Shape Type / Shutter weight(Kg)	V	T	I
[0-20[		x	x
[20-40[		x	
[40-60[	x		
[60-80[	x		
80<	x		

Table 2. Discovery tables (X = Existent solutions)

Parameters	1	2	3	4	5
Material	PP	PP5.5	ZAMAK	PA	POM
Constant tickness (mm)	[0-1[	[1-1.5[	[1.5-2[	[2-2.5[	[2.5-3[
Shape Type	V	T	I		
shape Width (mm)	[0-5[	[5-10[	[10-15[	[15-20[	25<
Insert length (mm)	[0-5[	[5-10[	[10-15[	[15-20[	25<
Insert width(mm)	[0-1[	[1-1.5[	[1.5-2[	[2-2.5[	[2.5-3[
Insert shape	square	Triangle	Trapez oïdal		
Shutter Weight (Kg)	[0-20[	[20-40[	[40-60[	[60-80[	80<
Over molded Steel bar	YES	NO			
New parts					

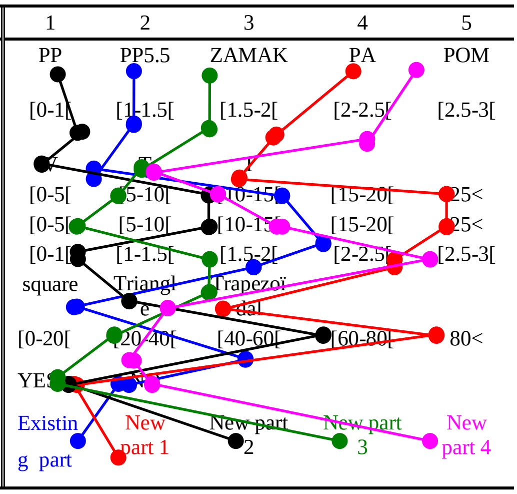


Table 3. Creative table using design topology and technical characteristics

3. Use case

3.1 Context application

This methodology is used in an industrial firm that is specialized in shutter components. The firm is a mid-range factory and has established a standard design method within the last few months. KBE applications are not used and parametric models are only just being deployed in the reseach and development office. A PLM tool is applied for Project-Product-Process functional and structural design, for the entire lifecycle and also for knowledge capitalization. This tool, called ACSP « Atelier Collaboratif de Suivi de Projet » has been developed at Belfort-Montbéliard University of Technology, at M3M laboratory. This PLM tool is specifically designed for adaptation to small firms, and is easily adapted to varying factory practices or history. Some work has already been done in the past on specification or on automatic project creation, which reduces routine time of project planning. Even if many references exist in a product family, when a new component of an assembly appears, the other components that are linked to this one are also likely to be changed. Our case study relates to a component called "V shape stopper" shown in Figure 16 and a rotative stopper (figure 6). We have applied our methodology to these components.

<u>The V shape stopper :</u> Our aim is to make an applications which can easily adapt to different variations of this window stopping mechanism. This window stopper is composed of one part. This part consists in a V shape which interacts with a stopping mechanism, called the "tulip". The V shape will vary depending on the size of the window blinds. However, due to the change in size of the window blind, many parameters of this V shape also change. In this section, we have started the first part of the methodology, which contains the decision support and the automatic model generation. As automatic model generation allows time to be saved, the user can undertake some additional studies in order to improve the model.

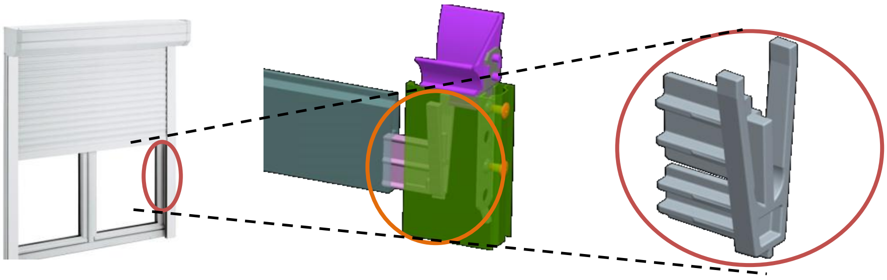


Figure 16. V-blade stopper part and assembly

For example, the V blade stopper is made of re-enforced plastic PP55 in order to have sufficient resistance in the V shape. The use of a plastic such as PP, PA or POM with a steel bar over moulded in it can reduce the component price. Therefore validations are needed and the user can discount other relevant solutions. Our model checks every parameter and tests a vast range of combinations. In addition, we have tried to formalize tacit knowledge such as formulae, constraints and relationships with the help of experts. This tacit knowledge cannot be easily formalized to be useable by everyone but after several meetings with the experts, some rules have been created and introduced in the model. From the tacit knowledge the following rules have been determined:

- Rule 1: In order to allow removal from the mould, the features need an appropriate draft;
- Rule 2: The design has to consider retraction in the mould according to the material;
- Rule 3: The part must contain features that avoid air bubbles;
- Rule 4: injection settings must be included in the following range : [X°C to Y°], [W to Z PSI];

Rules which deal with moulding settings will be used in the optimization loops. By implementing the range of possible settings validated by experts, the optimization tools will calculate the best case for the range entered. By selecting the target parameters for example the cycle speed with the optimal filling, the tool will indicate the best setting for the new part created in the KBE application.

3.2 Results

The KBE application was created thanks to “Kadviser”, an inference engine tool, using constraints propagation, coupled with the “ACSP” PLM tool, , which allows a semi-automatic creation of the knowledge embedded in the PLM tool and “mode frontier” as an optimisation tool. For instance, in the following Figure 17, the validation check value is the deformation compared to the material, the wall thickness, and the geometry.

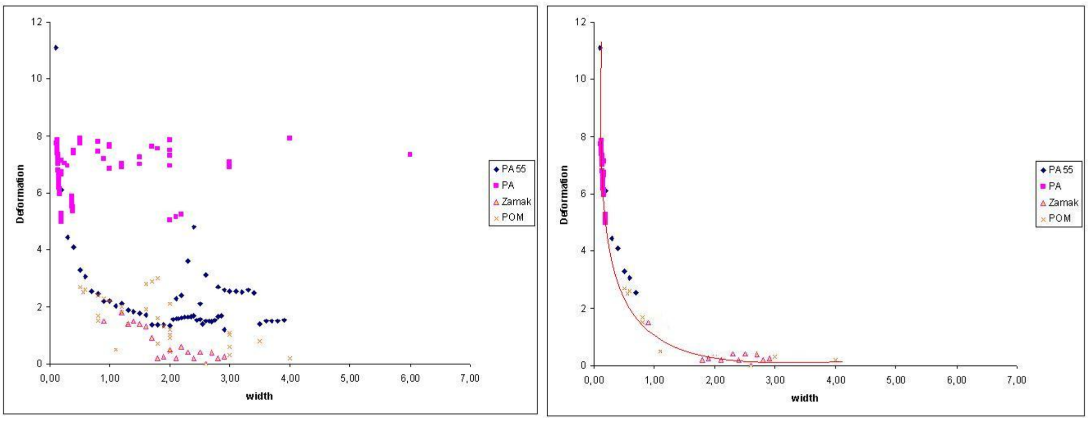


Figure 17. Points showing results of various creative parts and corresponding pareto frontier

The module allows the user to work beyond simply copying a new product onto an existing product but also creating a new concept. By using the existing range of parameters, the user can use the optimisation module to simulate a vast choice of an infinite combination of parameters. By targeting the parameters to be changed the calculation loops allow a lot of possibilities of new models to be analysed and checked for validity according to the model requirement. This Kadviser application allows a parameter table to be generated which contains both V-blade stoppers and corresponding moulding tools. Indeed, according to the material selected, the moulding tool will be adjusted according to the corresponding shrinkage values. Furthermore, the modifications are compatible with existing coolant ducts and ejection trays as the existing moulding tool contains exchangeable moulding print. Before using this methodology, the user had to create the whole mould print.

The rotative stopper : On this part the target was to reduce the manufacturing cost of this part. The creativity module has permitted to define a new concept by changing the material of the stopper, from Zamak 5 to PA 66 with 60% long glass fibers. The strenght has been validated by finite element and shapes optimisation loops. As a result, the material modification permit a cost reduction from 0.11 € by unit for the Zamak 5 to 0.015 € by unit for the PA66 (Figure 6).

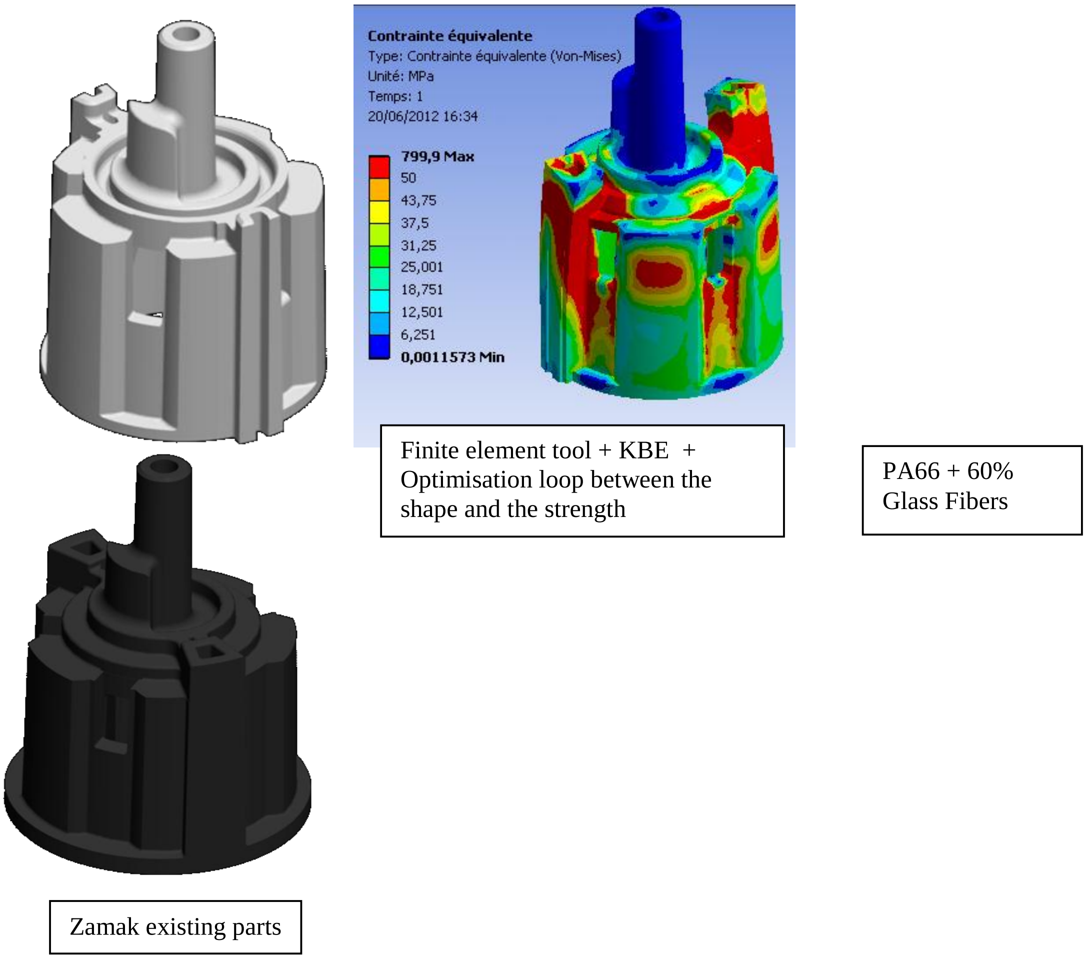


Figure 18. Creativity module used for material change validation

4. Conclusion

The decision support coupled with the automatic creation of the 3D model (including the manufacturing tools) according to the environment, allows a reduction of non value-added tasks. This reduction allows the user to devote more time to creative design. This article shows the first result of this methodology applied in a mid size firm, specialized in shutter components. The methodology was applied for plastic components, using top down design and KBE application including decision support. In an assembly or a sub assembly, these finite element calculation loops allow the best product for the chosen configuration at a particular time to be found. The configuration contains parameters which constitute a specific kind of knowledge configuration (vocabulary, semantic networks, etc.), that helps to create new data and information on the product, and at least, to make a record of it in a PLM tool. In the short term perspective, other applications will be created with other components, which could allow not only a reduction of time for creating a new component, but also could include if needed, a creative design time to test other concepts and other geometry.

References

Miles B.L., Swift K.G.,(1992) Working together, Manufacturing Breakthrough, Vol. 4, pp. 69-73.

Yeh R.T.(1992) , Notes on concurrent engineering, IEEE Transation on Knowledge Data Engineering, Vol .4, No. 5, pp. 407-414.

Stark, J, (2004) Product Lifecycle Management : 21st Century Paradigm for Product Realisation. London, Springer London Ltd. ISBN: 978-1852338107.

CIMdata Incorporated, (2009) "PLM Market Growth in 2008 'A Mid-Year Look in 2009-Weathering the Storm'", White Paper, August

Tichkiewitch, S. (1994). De la CFAO à la conception intégrée. Paris, FRANCE, Hermès. ISBN: 0298-0924.

Lu, S. C. Y., Elmaraghy, W., Schuh, G. et Wilhelm, R. (2007). "A scientific foundation of collaborative engineering." CIRP Annals - Manufacturing Technology 56(2): 605-634.

Baxter, D., Gao, J., Case, K., Harding, J., Young, B., Cochrane, S. et Dani, S. (2008). "A framework to integrate design knowledge reuse and requirements management in engineering design." Robotics and Computer-Integrated Manufacturing 24(4): 585-593.

Hubka, V. et Eder, W. E. (1988). Theory of technical systems: A total concept theory for engineering design (2nd revised and enlarged edition). Berlin, Springer-Verlag. ISBN:

Hauschild, M., Jeswiet, J. et Alting, L. (2005). "From Life Cycle Assessment to Sustainable Production: Status and Perspectives." CIRP Annals - Manufacturing Technology 54(2): 1-21.

Li, W. D. et Qiu, Z. M. (2006). "State-of-the-art technologies and methodologies for collaborative product development systems." International Journal of Production Research 44(13): 2525-2559.

Deneux, D. (2002). Méthodes et modèles pour la conception concourante. Laboratoire d'Automatique de Mécanique et d'Informatique industrielles et Humaines. Valenciennes, Université de Valenciennes et du Hainaut Cambrésis. Habilitation à Diriger des Recherches.

Skarka, W. (2007). "Application of MOKA methodology in generative model creation using CATIA." Engineering Applications of Artificial Intelligence 20(5): 677-690.

Swift, K. G. (2003). Process Selection: From Design to Manufacture, Butterworth Heinemann. ISBN:Matta and al., 2000]

Toussaint L., Lebaal N., Schlegel D., Gomes S., "Automatic Optimization of Air Conduct Design Using Experimental Data and Numerical Results", Int. J. Simul. Multidisci. Des. Optim., 4, 77-83, 2010, Published 21 July 2011.

W. Hsu, I.M.Y. Woon, (1998), "Current research in the conceptual design of mechanical products", Computer Aided Design, 30 (5) (pp. 377–389

Renbin Xiao, Yao Zub, Shunqi Mei, (2011) Creative product configuration design driven by functional features · Journal of Manufacturing Systems. Thursday, May 19,

D. Cavallucci, (2001), Integrating Altshuller's development laws for technical systems into the design process, CIRP Annals - Manufacturing Technology, Volume 50, Issue 1, 2001, Pages 115–120,

A. Hatchuel, B. Weil, (2003) A new approach of innovative design: an introduction to C-K theory, international conference on engineering design iced 03 stockholm, august 19-21,

Z. Wei, Y.X. Feng , J.R. Tan, J.L. Wang, Z.K. Li, Multi-objective performance optimal design of large-scale injection molding machine, Int. J. of Adv. Manufacturing Tech., 41, (2009) 242-249.

N. Lebaal, S. Puissant and F. Schmidt, Application of a response surface method to the optimal design of the wall temperature profiles in extrusion die, Int. J. Mat. Form., 38, (2010) 307-322.

H. Ou , P. Wang, B. Lu, H. Long Finite element modelling and optimisation of net-shape metal forming processes with uncertainties, Computers and Structures 90–91 (2012) 13–27.

Naceur, H., Ben-Elechi, S., Batoz, J-L. and Knopf-Lenoir, C. 'Response surface methodology for the rapid design of aluminium sheet metal forming parameters', Materials and Design, 29, (2008) 781–790.

M. Oudjene, L. Ben-Ayed, A. Delamézière, J.-L. Batoz Shape optimization of clinching tools using the response surface methodology with Moving Least-Square approximation Journal of Materials Processing Technology, 209 (2009) 289-296.