NTERNATIONAL DESIGN CONFERENCE - DESIGN 2010
Dubrovnik - Croatia, May 17 - 20, 2010.

DESIGN 2010

KNOWLEDGE REUSE: TOWARDS A DESIGN TOOL

A. A. Ammar, D. Scaravetti and J. P. Nadeau

1. Introduction

Just like large companies, small and medium-sized enterprises (SME) too must cope with staff turnover and see their most experienced workers retire, leading to a loss of knowledge. The challenge for these companies is to be able to capture that knowledge and to leverage it throughout the organization.

A small-to-medium sized enterprise (SME) is usually defined as one that has sales of less than $2 million annually and has fewer than 100 employees [Delaheye 2005]. A SME offers two advantages in initiating research on knowledge management. As Davidson and Griffin [Davidson and Griffin 2003] comment, small businesses have contributed many innovative ideas and technological breakthroughs to our society.

Moreover, design and knowledge have a very strong association: recollection and application of knowledge can be considered as a straightforward and practical design process [McMahon et al. 1998], [Foley et al. 1990]. It is estimated that the designers spend about 60% of their times for the search for information [Iyer et al. 2003]. By using design knowledge reuse and adopting a suitable methodology, design times should be reduced [Xiuzi et al. 2008].

It is in precisely this context that an SME producing articles of footwear wanted to start a project to optimize knowledge management: the aim was to set up a design methodology for new manufacturing processes, based on reuse of existing knowledge.

There are several methods suggested in the literature to assist with design reuse [Sivaloganathan and Shahin 1999]. However, these concentrate mainly on solutions that are available to large companies. These approaches are more difficult for SMEs to exploit because the tools required are relatively complex, the manager does not always have a lot of time available, there is a lack of financial resources in the company to set up these tools and also a lack of qualified staff [Herrmann et al. 2007], [Evangelista et al. 2010].

The aim of this research study was to provide a methodology adapted to the small business context, to formalize and capitalize on knowledge with a view to designing future processes. This methodology will be built around a knowledge based system. Developing such a system must meet at least two objectives: to store the accumulated knowledge and know-how of the SME, and to make it accessible, when required, to operators and designers so that they can then reuse it. Important factors like ease of access to the database, availability of technical support and relevance of the information used must then be taken into consideration.

Efficient exploitation of existing knowledge is always dependent on the way the knowledge has been structured and capitalized [Shahin et al. 1999]. A method has been suggested to analyze existing knowledge linked with the processes used in the SME [Ammar et al. 2009]. In this paper we present the design methodology in place in the SME, and also the architecture of the knowledge base applied

to solving design problems. We also specify the reasoning method required to access the base and obtain design solutions to carry out a given function.

2. Design methodology

A design methodology is a sequence of design activities starting at the design requirement and going through to a definition of one or several architectures of the designed artefact [Reymen 2001]. In the context of this work, this is a process to guide the SME in designing new manufacturing techniques.

Several descriptions of design methodologies exist in the literature. Some authors propose sequential design processes based on a chronological succession of phases [Pahl and Beitz 1996], [Ulrich and Eppinger 1999]. These types of processes are still used in companies where development deadlines are not imposed by the market and the competition; however this is not the case for most companies. Other authors define iterative processes [Cross and Rozenburg, 1992], [Altshuller 1988]. In this type of modeling, the process is no longer seen as a linear succession of phases but rather a set of problems to be resolved in succession.

In this study, we propose a sequential but iterative design methodology, based on reusing existing knowledge in the search for design solutions. The iteration and reuse aspects are integrated in order to meet the need to impose deadlines and reduce design and development costs. As the flow chart in figure 1 shows, our design methodology is based on four phases:

- External functional analysis: this is the formulation phase to determine the characteristics of the technique to be designed. The final product of this phase consists of the functional specification requirements for the technique.
- Sequential analysis of the manufacturing process: this is the phase where the elementary functions of a technique are identified, and these are then the input elements for the knowledge base. We represent a technique as a chronological succession of tasks. Next, each task is broken down into sub-tasks then into elementary functions. An elementary function in the task model is an elementary action that cannot be or is not to be broken down further. It is expressed in the form of a verb plus one or two complement(s) [Hirtz et al. 2002].
- Search for concepts: this phase involves the use of a knowledge base. The input element is the elementary function. The aim of reuse is to recover all relevant information about a function already known in the SME, in order to implement it. The structuring and use of the knowledge base are presented next. In the case of a new function (not known in the company) or if the solution that has been found is not satisfactory, the concept search will be based on creativity. Different tools can be used in this phase such as MAL'IN (computer assisted innovation tool) [Pailhes et al. 2007-1]. The concepts that are chosen must then be validated.
- Embodiment Design: this phase consists of defining the architecture of the manufacturing process, by setting out the different concepts involved and trying to find ways of incorporating them together. We are still working on developing this phase which requires an heuristic approach to help the designer.

In the next paragraph, we present the architecture of the knowledge base and how to use it in order to obtain design solutions for a given function.

3. Structuring the knowledge base

The purpose of the knowledge base is to provide the designer with all the relevant information about a given function, so that it can be successfully carried out. What is more, a system like this can offer various solutions for the same function, something the designer usually does not have time to do.

In our case, the input element to the base is the elementary function, expressed in the form of a verb plus one or two complement(s). However, a function is never, and probably never will be, expressed in exactly the same way by two different designers. Indeed, the same function can always be expressed in several different ways by using, for example, two synonymous verbs or two complements for the same physical characteristics. In order to facilitate data input and information extraction, the knowledge base must use a standard and restricted vocabulary to ensure both uniqueness and ease of structuring, but it must also ensure exhaustivity in the description [Stone and Wood 2000].

In order to resolve this problem, we have drawn up a verb base and a complement base. We have also studied the appropriateness of each verb and complement combination.
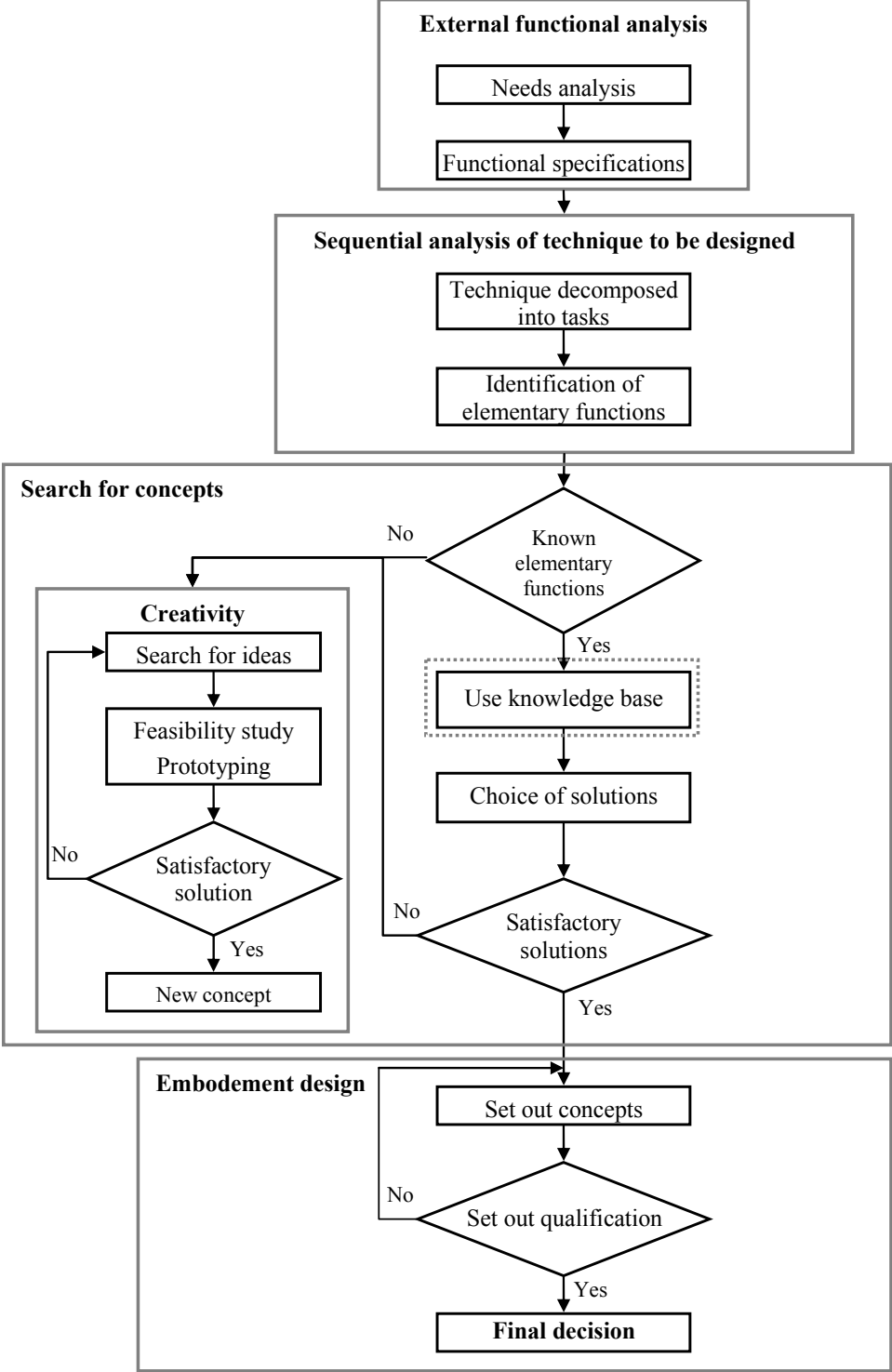

Figure 1. Design process for new manufacturing processes, using a knowledge base

3.1 Development of a verb base

In the phase of capitalizing on the knowledge associated with the techniques used by the SME, the structuring of technical solutions for a given function was based on an energy approach [Ammar 2009]. It is based mainly on the first law of technical system evolution defined in the TRIZ method [Altschuller 1984], [Savransky 2000] and then taken up by Nadeau et al. [Nadeau et al. 2005], [Doré et al. 2006], [Pailhès et al. 2007-2]. This law states that for a function to be carried out requires the transformation of energy by an association of components, which are:

- Functional components (converter (T), transmitter (T), operator (C or T);
- Control - command (C/C) components;
- An energy source (S) which may be internal or external to the system
- Interaction components (between components or between components and reference).

Figure 2 describes this succession of components. The energy is initially provided and stored by a source component (S). Then it is converted by a converter (C) component. It is then transmitted by a transmitter (T) component. An operator (O), who may be either a converter or a transmitter, carries out the action. The system is optimal when it contains a control/command function carried out by a component controller. The components are positioned in relation to a reference which may be internal or external to the system.
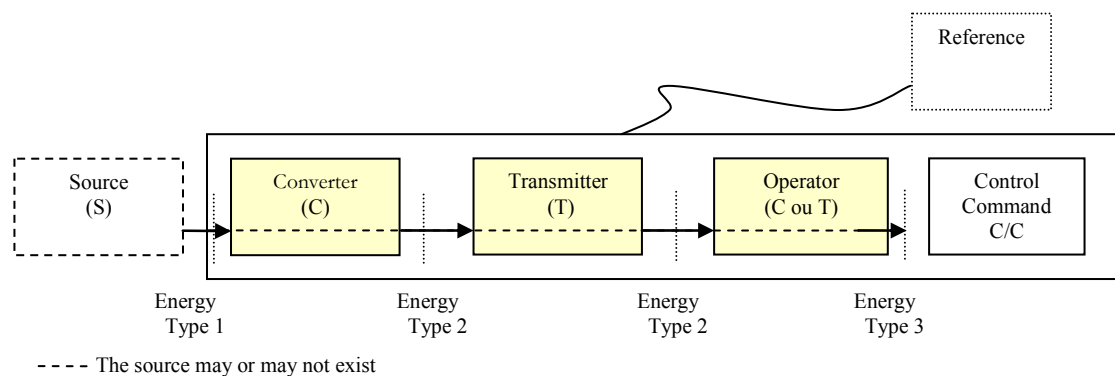

- - - - The source may or may not exist

Figure 2. Carrying out a function in terms of energy

A primary class of verbs was defined in relation to this view. It includes the basic function of each type of component (table 1).

Table 1. Correspondence between functions in terms of energy

Components linked with the primary class	Primary class of verbs
Converter (C)	Convert
Transmitter (T)	Transmit
Link to the reference (R)	Link to the reference
Source (S)	Supply
	Stock
Controller (C/C)	Control

Based on studies by Sallaou [Sallaou et al. 2009] and Hirtz [Hirtz et al. 2002], this primary class was decomposed into a secondary class, a tertiary class and a quaternary class (table 2). These classes corresponded to semantic levels that were more and more precise. The quaternary class was enriched by verbs relating to jobs in the partner SME, a footwear manufacturer (e.g. to coat, sew, etc.).

Table 2. Extract from Verb Base

Components	Functions			
	Primary class	Secondary class	Tertiary class	Quaternary class
Converter	Convert	convert		Transform
Transmitter	Transmit	Displace	Displace in translation	Slide, translate, move forward, move back, Rise, shift, descend
			Displace in rotation	Turn, pivot, return, roll, fold, turn down, fold up, roll up, spool,
			Transfer	send, lower, transport, discharge, eject, blow, press, draw, canalize, tighten, rub, gum, support, hammer, bring, inject, recover, absorb, attract, pump, evacuate, crush, vibrate,
			Disperse	pulverize, propagate, dissipate
			Pose	spread out, cover, coat, paste, extend, apply, Place, set up,
			Take	hold, raise, carry, remove, collect, carry, raise,
		Reproduce	reconstitute,	Print, photograph, copy, corrugate, engrave, mark, sinter, form, duplicate, carve,
		assemble	sew	prick, embroider, hem, suture, scallop, thread
			Link	nail, weld, aspire, attach, connect, screw, group, stick, amalgamate, link, rivet, mix, unit
			Join	Connect, crimp, silver, branch
		Separate		cross, divide, sort, release, extract, dissociate, insulate, cut out, slice, filter,
		Adapt	Increase	Accelerate, add to, enlarge, amplify, grow, raise, put up, intensify, rise, multiply,
			Decrease	drop, reduce, thin, compress, deflate, narrow, remove, melt, empty, compact
			Change	modify, reverse, adjust, correct, deform, heat, refresh, liquify, reactivate, dry, evaporate, humidify, crush, lubricate

3.2 Development of a complement base

As shown in figure 3, the definition of a function is any mechanism by which the transformations of one basic element (Matter, Energy or Signal) into another occur in an entity [Henderson and Taylor 1993]. This definition is used to express functions at different levels of the functional decomposition. The definition of the function as being based on identifying matter, energy and information (signal) as the basic elements has been adopted by other authors [Qian and Gero 1996], [Yang and Salustri 1999]. The description of the function is expressed as a verb and a complement. The complement represents the appropriate functional flow, which may be energy, matter or information (signal).

By analogy with the verb base, we defined a primary class of complements consisting of the three basic functional flows: energy, matter and information. This primary class was then broken down into a secondary class in which we specify the different types of each flow. Next, we defined a tertiary class in order to characterize physically each element in the 2nd class. We limited ourselves to the physical characteristics of the elements associated with matter: a solid, for example, could be preformed or it could be a film (negligible thickness), or in the form of balls or powder. Next, depending on the case in question, three binary characteristics could be added to complete the

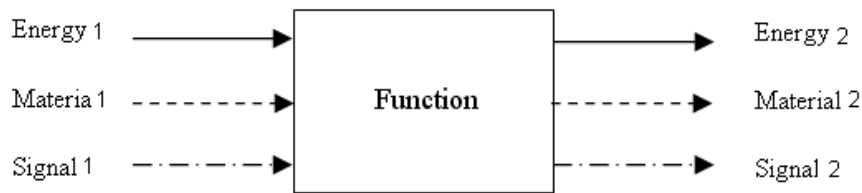description: rigid/flexible, porous/non-porous, compressible/non-compressible.

Figure 3. Representation model of function and flux (Henderson et al, 1993)

Thus we have developed a database of generic complements on several levels. A fourth class has been added to the database which corresponds in our case to complements relevant to job skills in the partner SME (e.g. tread, coating, etc.). This last class can be specifically adapted to different companies. The complement base is shown in table 3.

Table 3. Complement base

Complements						
Primary class	Secondary class	Tertiary class				Quaternary class
Energy	Translation mechanics					
	Rotation mechanics					
	Pneumatic					
	Hydraulic					
	Thermal					
	Electric					
Matter	Solid	Preform	Rigid	porous		Form, posage
				Non porous		Heel, top lift, insole
			Flexible	Compressible	Porous	Foam, first foam
					Non porous	tip
				Non compressible	Porous	
					Non porous	Sole, suction pad
		Film	Rigid	Porous		Board, first board,
				Non porous		midsole, button
			Flexible	Porous		Fabric, adhesive film, edge, shank
				Non porous		Latex membrane, silicon
		Balls	Rigid			Balls of adhesive, PVC granules
			Flexible			paste
		Powder				polyamide
	Paste, Gel					Putty, grease
	Liquid	Newtonian				aqueous adhesive, solvent
		Non Newtonian				cyano adhesive
		Emulsion				
	Gas	Mist				
		Saturated vapor				
		Overheated vapor				
Information						Text, picture

3.3 Verb-complement association

In our procedure, the input element to the knowledge base is the basic function, consisting of a verb plus one or two complements. It is not always possible to combine the two types of terms, as some combinations may be meaningless. When consulting the knowledge database, only functions that are

DESIGN INFORMATION AND KNOWLEDGE

semantically correct should be used. The problem that we have here is to identify semantic relationships between verbs and objects which, in our opinion, should be taken into account when the knowledge base is created. These relationships are considered as fundamental so as to associate each verb exhaustively with a set of compatible complements.

In our case, semantic compatibility was studied for each verb in the database. For each verb we identified all the complements that were compatible down to the tertiary level. Table 4 shows an extract from this study.

Thus, each possible verb/complement combination represents an elementary function, to which can be linked all the relevant information needed to carry it out.

Table 4. Verb/complement combinations

VERB BASE				COMPLEMENT BASE																										SIGNAL
verbs				ENERGY						MATTER																				
										SOLID												PASTE	LIQUID			GAS			
										PREFORM						FILM				BALLS		POWDER		New-tonian	Non newtonian	Emulsion	Mist	Saturated vapor	Overheated vapor	
CLASS 1	CLASS 2	CLASS 3	CLASS 4	MEC T	MEC R	PNEU	THER	ELEC	HYD	RIG	SPLE	POR	NPOR	COMP	NCOMP	RIG	SPLE	POR	NPOR	RIG	SPLE									
Transmit																														
	Displace																													
		Displace in Translation																												
			Slide																											
			Translate																											
			Move forward																											
			Move back																											
			Rise																											
			shift																											
			Descend																											
		Displace in Rotation																												
			Turn																											
			Pivot																											
			return																											
			roll																											
			fold																											
			turn down																											
			fold up																											
			remplier																											
			roll up																											
			spool																											
		Transfer																												
			lower																											
			send																											
			transport																											
			discharge																											
			eject																											
			blow																											
			press																											

4. Searching into the knowledge base

A knowledge-based system is a complex structure which is supposed to guide the user in solving a design problem. Such a system consists of a knowledge base and an inference engine [Baxter et al., 2007]. The user, confronted with a specific problem, searches the system for possible solutions. In our case, he will enter an elementary function in the form of a verb and complements. The system will give the technical solutions associated with this verb-complement combination.

In this part we will describe how to search the knowledge base, a procedure summarized in the flow chart below (fig 4).

As we mentioned earlier, the designer begins by entering a verb or selecting it from the quaternary class list. If the verb already exists in the database, the designer must then add a complement. If not, the tertiary class of the verb base will then be offered. Then, the user selects either one of the verbs from this class which he considers to be synonymous with the verb he entered at the beginning, or moves on to the secondary class and if necessary the primary class.

When the verb has been selected, a list of compatible job-related complements (4th class) will be proposed. The designer then has two possibilities:

- Either the complement he wants to add exists in the list proposed at the quaternary level. In this case, the designer selects it and will then obtain the technical solution output associated with the verb/complement combination selected.
- Or the complement he wants to add does not exist in the proposed list. In this case, the designer runs through the generic complement base, starting at the primary class, to define the physical characteristics associated with the complement. For example, the user may define his complement as solid/preformed/rigid/non-porous matter. At this point, a list of solutions will be provided.
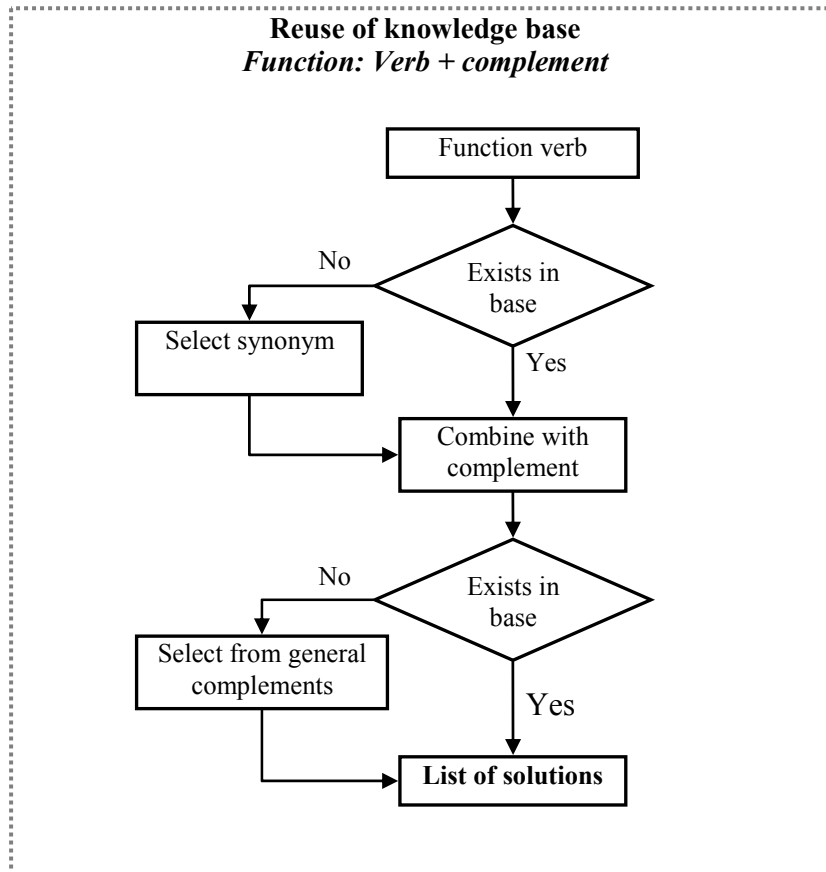
Figure 4. Flow chart for searching the knowledge base

5. Conclusion

We have presented a design methodology based on reuse of existing knowledge. This work was undertaken in partnership with a small footwear manufacturing business. The final aim is to produce a computer assisted design tool for new manufacturing techniques. The methodology we propose is organized around a system that uses a knowledge base. The basic input element into the database is the elementary function, expressed in the form of a verb and complement. We have developed a database of verbs and one of complements. Both are decomposed into four classes, each corresponding to a more and more precise semantic level. Identifying the semantic relationships between the verbs and the complements was taken into account when constructing the knowledge base in order to associate each verb exhaustively with a set of compatible complements.

Based on a verb-complement association, the system provides output of all the possible technical solutions. The principle behind using the knowledge base was designed so that whatever the level of interrogation (based on job-related terms or using generic terms), the system can provide compatible solutions.

This process can be adapted to any company, but they will have to enter their own verbs and job-related complements (quaternary classes).

The overall design procedure presented in the flow chart figure 1 does not give details of all the phases. We are currently working specifically on design heuristics, drawing on the experience of the SME. The aim is to produce rules that will facilitate the aggregation of functions and thus simplify the architecture of the manufacturing process so that all the desired tasks can be carried out.

Future studies in this field will focus on producing the computer tool, with the constraints of ensuring that it is appropriate for use in the SME: it should be simple and quick to use and update, accessible to staff who are not specialists in design, in capitalization or innovation. Lastly, we want to identify the

DESIGN INFORMATION AND KNOWLEDGE

roles of different users, giving access as appropriate so that data in the knowledge base can be modified directly.

References

Ammar, A.A, Scaravetti D., Nadeau J.P., " Knowledge capitalizing and analyzing for the conception of manufactural processes ", Third International Congress Design and Modelling of Mechanical Systems, Tunisia, 2009.

Altshuller, G., "And suddenly the inventor appeared", Technical Innovation Center,1984.

Altshuller, G., "Creativity as an exact science", Gordon and Breach, New York, 1988.

Baxter, D., Gao,J., Case, K., Harding, J., Young, B., Cochrane, S., Dani, S., "An engineering design knowledge reuse methodology using process modelling", Research in Engineering Design, Vol.18, No.1, 2007, pp 37-48.

Cross, N., Rozenburg, N.,"Modelling the Design Process in Engineering and in Architecture", Journal of Engineering Design, Vol.3, No.4, 1992, pp 325-337.

Davidson, P., Griffin, R.W., "Management: An Australasian Perspective (2nd edn.)", John Wiley & Sons, Brisbane, Australia. 2003.

Delahaye, B.L., "Knowledge Management in an SME". International Journal of Organisational Behaviour, Vol.9, No.3., 2005, pp 604-614.

Doré, R., Pailhès, J., Fischer, X., Nadeau, J.P., "Identification of Sensory Variables towards the integration of User Requirements into Preliminary Design", International Journal of Industrial Ergonomics, Vol.37, No.1, 2006, pp 1-11.

Evangelista, P., Esposito, E., Lauro, V., Raffa, M., "The Adoption of Knowledge Management Systems in Small Firms", Electronic Journal of Knowledge Management, Vol. 8, Issue 1, 2010, pp 33-42.

Foley, J., Van Dam, A., Feiner, S., Hughes, J., "Computer graphics: Principles and practice", Addison-Wesley Longman Publishing Co., Boston USA, 1990.

Herrmann, T., Herrmann, G.B., Jahnke, I., "Work Process Oriented Introduction of Knowledge Management: Reconsidering the Guidelines for SME", Proceedings of 7th International Conference on Knowledge Management - I-KNOW '07, Graz (Austria), 2007.

Henderson, M. R., Taylor, L. E., "A meta-model for mechanical products based upon the mechanical design process", Research in Engineering Design, Vol.5, No.3-4, 1993, pp 140–160.

Hirtz, J., Stone, R., McAdams, D., Szykman, S., Wood, K., "A Functional Basis for engineering Design: Reconciling and Evolving Previous Efforts", Research in Engineering Design, Vol.13, No.2, 2002, pp. 65-82.

Iyer, N., Kalyanaraman, Y., Lou, K., Janyanti, S., Ramani, K., "A reconfigurable 3D engineering shape search system part I: Shape representation", Proceedings of ASME design engineering technical conferences, computers and information in engineering conferenc - DETC'03, Chicago, 2003.

McMahon, C., Browne, J., "CADCAM, principles practice and manufacturing management", Addison Wesley Longman Publishing Co., 1998.

Nadeau, J.P., Pailhes, J., Dore, R., Scaravetti, D., "Analyser, qualifier et innover en conception par les lois d'évolution TRIZ", Proceedings of 6ème Congrès International de Génie Industriel, Besançon, 2005.

Pahl, G., Beitz, W., "Engineering Design: A systematic approach", second Edition, Springer-Verlag, London UK, 1996.

Pailhes, J., Nadeau, J.P., "Innover en conception par les Méthodes d'Aide à L'INnovation MAL'IN", Proceedings of 7ème Congrès International de Génie Industriel, Trois Rivières, Canada, 2007.

Pailhès, J., Sallaou, M., Nadeau, J.P., "Knowledge base formulation for aided design tool", Trends and Recent Advances in Integrated Design and Manufacturing in Mechanical Engineering II, edited by Serge Tichkiewitch, Michel Tollenaere et Pascal Ray, 2007, pp. 231-244.

Qian, L., Gero, G. S., "Function-behavior-structure paths and their role in analogy-based design", Artificial Intelligence for Engineering Design, Analysis and Manufacturing, Vol.10, No.4, 1996, pp. 289-312.

Sallaou, M., Pailhès, J., Nadeau, J.P., "Structuration fonctionnelle d'une base de composants en conception préliminaire", Proceedings of 19ème Congrès Français de Mécanique, Marseille, 2009.

Reymen, I.M.M.J., "Improving design processes though structured reflexion- A domain independent Approach", Ph.D thesis, Eindhoven, The Netherlands, 2001.

Stone, R.B., Wood, K.L., "Development of a Functional Basis for Design", Journal of Mechanical Design, vol. 122, No.4, 2000, pp. 359-370.

Savransky, S. D., "Engineering of creativity: Introduction to TRIZ Methodology of Inventive Problem Solving", CRC Press, 2000.

Shahin, T.M.M., Andrews, P.T.J., Sivaloganathan, S., "A design reuse system. Proceedings of the Institution of Mechanical Engineers, Part B", Journal of Engineering Manufacture, Vol.213, No.6, 1999, pp. 621-627.

Sivaloganathan, S., Shahin, T.M.M., "Design reuse: an overview", Proceedings of the Institution of Mechanical Engineers - Part B, Engineering Manufacture, Vol.213, No.7, 1999, pp. 641-655.

Ulrich, K. T., Eppinger, S.D., "Product Design and Development", McGraw-Hill Education, 2nd edition, 1999.

Ye, X., Liu, H., Chen, L., Chen, Z., Pan, X., Zhang, S., "Reverse innovative design—an integrated product design methodology", Computer-Aided Design, Vol.40, Issue 7, 2008, pp 812–827.

Yang, B., Salustri, F.A., "Function Modeling Based on Interactions of Mass, Energy and Information", Proceedings of the Twelfth International Florida Artificial Intelligence Research Society Conference, American Association for Artificial Intelligence, 1999.

D. Scaravetti, Associate professor
Arts & Métiers ParisTech, TREFLE laboratory
Esplanade des Arts et Métiers, 33400 Talence, France
Telephone: +33 5 56 84 54 22
Email: dominique.scaravetti@ensam.eu