NOVEL METHOD TO ASSIST HUMAN CREATIVITY IN THE EARLY PHASES OF THE DESIGN PROCESS

Piros, A.
Department of Machine and Product Design
Budapest University of Technology and Economics (BME), Hungary
piros.attila@gt3.bme.hu

Vidovics, B.
Department of Machine and Product Design
Budapest University of Technology and Economics (BME), Hungary
vidovics.balazs@gt3.bme.hu

ABSTRACT

There have been several methods developed to describe and support the early phases of the design process, still there remains a strong need for human creativity. Design projects differ in complexity and design type, as well as in the need for divergent thinking. In new product development projects the generation of novel and useful (i.e. creative) solution variants is essential, while the evaluation and selection of the most suitable alternatives is challenging, too. This paper aims at describing different possibilities to algorithmize and support the early phases of the design process from the perspective of generation and evaluation of solution variants. The paper introduces a new alternative to support solution generation in the early phases. The method is applicable to abstract product concepts, principle solutions and technical concepts, and can also be applied in component-level embodiment design tasks which have less dependence on human creativity. The main advantage of the approach is the possibility of computer support as the process is relatively easy to algorithmize. The applied work-flow could be adapted in computer algorithms and under certain circumstances could substitute activities normally requiring human creativity. The method in question is based on the generation of the complete solution space which is later evaluated with fuzzy based methods. The preliminary and partial tests on this novel method have been carried out on data from a lately design project, and those preliminary results are presented in this paper.

KEYWORDS

industrial product innovations, product development methodologies, solution space, fuzzy method, creativity

1. INTRODUCTION

According to the commonly accepted phase models in design methodology (e.g. the model described by Pahl & Beitz [1]) the design process begins with the problem definition phase. If it is a new product design project (e.g. to serve needs in new ways) the design brief should be in line with the marketing concept. Once the problem specification is ready the function structure is generated, then applicable principle solutions are collected to fulfill the functions; this is called the conceptual design phase. It is the embodiment design phase where overall layout design is determined and preliminary forms are designed. According to the experience of the authors, designers tend to narrow down the number of design alternatives too early. In the case of new product design projects it is essential to keep product possibilities and concepts open as wide as possible and for as long as possible in the early steps. Also, the authors observed that the more principle solutions, conceptual solutions and product proposals are generated during the embodiment design phase the least of the solution space remains uncovered. It seems it is good practice to keep a reasonably high number of different variants up to the end of the embodiment design phase in order to represent a variety of different ways of feasible solutions. N.B. not only the generation of solution variants is challenging, but the proper evaluation and selection too. It is extremely important to try to generate or discover novel, surprising combinations of already known (elements of) solutions, as this will lead to creative solutions in the end.

In the Industrial Design Engineering (IDE) practice the authors have observed several barriers which hinder designers in generating a large number of solution variants in the early phases of the design process. Psychological inertia, early judgment, lack of skills in structured thinking, burn-out, not being able to distinguish important from not important, not being able to see what is under the surface, etc. all seem to render the creative processes more difficult.

Also, designers tend to refuse to carry on with numerous design alternatives in parallel for several possible reasons. One of those is obviously when they have their own personal favorite ideas, and they tend to run ahead into detail design already. From the design management perspective the design paradox should be taken into consideration: in a company environment the farther the project is elaborated the more expensive is to realize changes. [2] The designers are more and more about the design problem as the project evolves, therefore there might be additional possibilities to reduce risk.

Furthermore, in the embodiment design phase there is another phenomenon which requires attention. Obviously, the evaluation of the design variants through the design process could only be carried out according to their current state of development, either it comes to the assessment of feasibility, functionality, or viability. Surprisingly, in the case of a possible future deterioration in value, performance, cost, etc. of a previously selected variant companies tend to start optimizing the current alternative. This generally happens despite the fact that the company always has an option to loop back to another recent solution variant.

Ideally there should exist a method, which supports the broad generation of the solution space, at least on the abstract level, and at the same time enables a systematic evaluation of the variants and their features or characteristics on the resulting big data. The continuous book-keeping of the qualities of the solution variants might not require the actual selection, in consequence a radical cut in the number of alternatives, therefore providing the possibility to elaborate sufficient number of concepts into the embodiment design phase.

2. CREATIVITY IN THE DESIGN PROCESS

Product development, more specifically the design process could be considered as a complex problem solving procedure of non routine problems [3]. Due to the limitations of this paper authors do not list a number of different interpretations, more simply use a widely accepted simple definition to creativity that it is “a mental process involving the generation of new ideas or concepts, or new associations of the creative mind between existing ideas or concepts” [4, p.57]. There is no debate that creativity plays significant role in the design process, and the importance. [5] If the design process is targeted at designing a new product, creativity starts to play the lead: “without creativity [product] innovation is not possible” [6].

In brief we need to shed some light on the dependence of the new product design project on creativity, and also on what extent creativity has an influence on the different design phases. Note that the necessity for creativity in the project is well predicted by the type of the design problem [2], while another factor might be the targeted degree of innovation [7]. For the ultimate success in product innovation creative individuals, creative teams and creative organization are required [6].

2.1. Product specification

It is above all question that problem clarification is a key step in the design process, and either the market demand or the novel technology is given as the starting point the set-up of the initial design problem specification will require human creativity. In the understanding of the authors the design brief is already a creative product in itself. To a certain extent the design brief could be considered as an abstract product, as the designer is aware of the product’s functions and benefits or in the other case the working principle, yet might not know exactly how the product would look like.

2.2. Principle and conceptual solutions

The models of human problem solving processes are reflected in the descriptive design process models. [8] This has significant importance in the concept generation phase. In most of the process models there is a step called “search for alternatives” which refers to the usage of either external sources or performing internal search activities, called ideation. [9] The majority of the design tools supporting the sub-processes of ideation and solution generation builds upon human creativity and require a vast number of solution variants to be generated in the divergent steps. [10] The firm belief behind those methods is called the “quantity breeds quality principle” [11].

Human behavior in general prefers heuristic problem solving against creative problem solving [12], which could be a pitfall in the design process. This natural born “economic” or “lazy” behavior could be got around with establishing a situation, where all the building components of creativity are present, e.g. the designer does not have to create new associations or connections, they only need to recognize them.

2.3. Evaluation in the design process

In the convergent (evaluation and selection, screening) steps creativity is also needed e.g. in the form of preparing the adequate assessment criteria, identifying the error or failure modes, etc. A highlighted area is the complex assessment of innovation potential, which is in close relation with creativity [5]. In the topic of the early assessment of the innovation potential there can be found a few studies [13]. The authors share the approach of Amabile [6] that creativity is a necessary but not sufficient condition for innovation, therefore the creative character of the design outcome well predicts the innovation potential [5].

2.4. Building blocks of creativity

Within the framework of this paper the focus will be on the creative outcome, rather than the creative individual or the creative organization. According to the majority of authors there seems to be an agreement that creativity is the product of *novelty* and *value,* e.g. [14, 15]. A few sources mention the *surprise* factor as well, [16]. Simply it means that both first or all ingredients are needed to call an outcome creative.

Novelty is a relative notion, it refers to the newness in comparison with the solutions already seen or being available. It might have a multi-fold meaning; a target or solution could be new to the individual, to the organization, to the customer, or to the market. [14]

Value refers to the balance of expected benefits and the negative effects of the product. It is a relative notion, it depends on the design objectives. For example, a proposal could be novel, but without the (marketable) functional potential, it remains only novel, not creative. [15]

Surprise is not mentioned in all creativity models as a building factor. Where is, it is defined as something that is unexpected or different from the preconception. [16]

3. DESIGN METHODOLOGY CONSIDERATIONS

In the design process a set of target criteria, generally referred to as the list of requirements or design protocol, is used to govern the process, ideally this is identical to the assessment criteria being used at the decision points of the process. [2] Note that not every criterion is applicable in each phase of the development simply because the level of detailing might have not reached a state to be able to confront the values to the measures. One may think it is straightforward for the designer in the design process to follow the same criteria both when searching for solutions and when evaluating and screening those solution variants. However, the case in reality is not that simple, partly because the requirements represent a complex system. Therefore, in the approach of the authors the appropriate adjustment of the driving requirements (so the assessment criteria as well) to the given state of development has a significant role. In each phase the relevant and applicable requirements have to be selected.

3.1. Solution space generation

Creative problem solving is sometimes considered as the ability to make short-cuts upon unconscious intuition rather than systematically generating and evaluating all possible solution variant alternatives from the elements. [15] Despite the fact that computing capacities are virtually unlimited, the solution space generation has to be carried out carefully to avoid ending up with unprocessable amount of data. Also, according to the experience of the authors usually 3 to 5 core design targets (functions, features) should be kept in focus in the early phases of the design process. It is proposed to generate the solution space accordingly. Oppositely with the iterative and compromising / optimizing character of the design process, here a full solution space generation and appropriate evaluation method is proposed.

3.2. Evaluation of variants

Authors are positive that in the case of new product design projects in the early phases the design alternatives have to be confronted with a few number of key factors: the innovative element, the future acknowledged value has to be dealt with first, which in this approach would mean the measurement of the *creative factor*. Consequently once the solution space is generated, novelty and value should be assessed.

4. THE FUZZY METHOD

There are a number of possible computational intelligence methods available to support product concept generation and evaluation. [17] Fuzzy logic provides effective means of dealing with the approximate and inexact nature of the real world. Fuzzy logic is a form of many-valued logic; it deals with reasoning that is approximate rather than fixed and exact. Compared to traditional binary sets (where variables may take on true or false values) fuzzy logic variables may have a truth value that ranges in degree between 0 and 1. Fuzzy logic has been extended to handle the concept of partial truth, where the truth value may range between completely true and completely false. [18]

A typical fuzzy membership function results on its output a number between 0 and 1. Zero means that the studied value is totally outside the set or range. 1 indicates that the value is fully inside the range. Any other value between 0 and 1 shows the ratio of the membership. A typical fuzzy inference system has fuzzy membership functions to handle the input and the output data and also has rules to control the connections among the input and the output data (as illustrated on Figure 1).

The application of the fuzzy sets method provides a good opportunity to handle the uncertainties in the design process mentioned in 3.1 and 3.2 [19]. The method is “human thinking friendly” because only some simple questions have to be answered and the fuzzy membership functions can be set up. Furthermore, fuzzy processing is fast and uses computational resources in a considerate manner; although the number of solutions can be quite high computers nowadays can handle this challenge.

In scientific literature only a small number of applications of fuzzy-based solution generation and selection methods are reported. [20-25] Although very sophisticated methods have been described in recent works, in this work the authors propose a very simple fuzzy-based algorithm with creativity in focus in order to test the principle of the method and to shed some colour on the applicability in the field of design creativity.

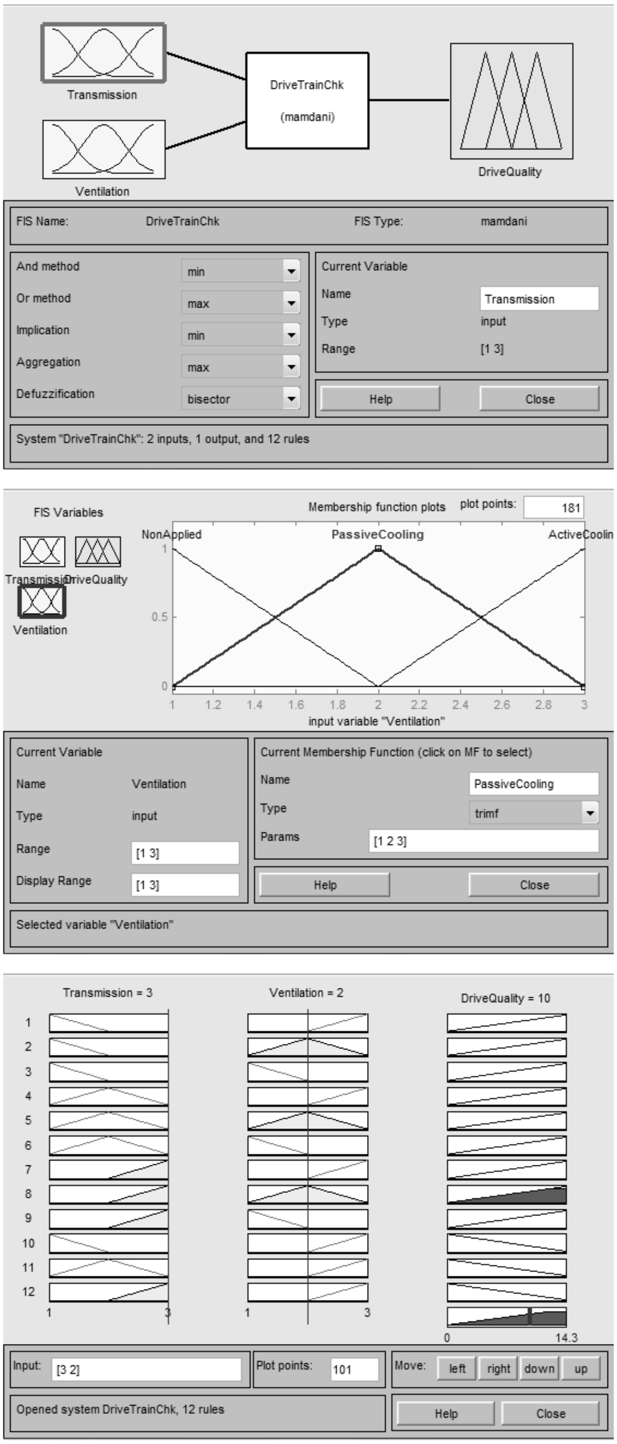


Figure 1 Typical fuzzy inference system in MATLAB environment with fuzzy membership functions in the input range and rules among the membership functions.

5. THE PROPOSED METHOD FOR SOLUTION SPACE GENERATION AND EVALUATION

5.1. Substitution of human creativity

In some specific cases human creativity can be substituted with a suitable algorithm in the generation and evaluation of design solutions. The exhaustive generation of the solution space has earlier proved its usability in different fields of science. This way of generation of the solution space is a well-known method in the field of molecular chemistry [26] and in DNA research [27]. Authors propose the usage of the same approach in the early phases of the design process.

Typically, if so, solution space is generated in the conceptual design phase on the basis of functions and partial solutions as the computerized extension of the Zwicky Morphological Chart (MC) method [28]. However, there is the opportunity to use this method anywhere in the design process where the descriptive or prescriptive models indicate divergent steps or tasks. For instance, in the embodiment design phase usually there are two alternative ways to find solution. On the one hand by the recombination of existing components and parts could lead to a solution. On the other hand the modification of the parameters of an existing solution variant leads to a new design version of the product in question.

5.2. Evaluation of creativity

Measuring, evaluating and mathematical modelling of human creativity is really challenging in the design process, and is a current topic amongst scholars [15] and practitioners. As already mentioned in 2.4 a creative solution usually has two main components: novelty and value. To describe, specify and handle these two properties is a prerequisite for the evaluation of the design alternatives, and is indeed a problematic task.

The fuzzy method makes it possible to define different categories of these properties. In a fuzzy inference system the relationships and rules between the different categories can also be properly defined. Both human creativity in the design process and the human influence in the evaluation procedure could be handled with the fuzzy method. In this case the fuzzy method can handle the human input and the calculated parameters as well.

6. CASE STUDY: HANDBLENDER DESIGN PROJECT

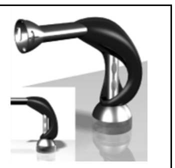
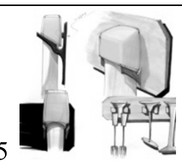
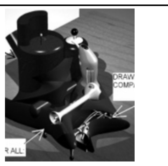
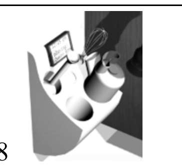
6.1. Methodology

For this research a European Global Product Realization (EGPR) industry-academia project was chosen from year 2010. The input data has been collected from the student team reports covering the specification phase, the conceptual design phase, and also from the embodiment and detail design phases. As it is presented in 5.1. and 5.2. in details, the focus was on the systematic support of divergent and convergent tasks.

6.2. Introduction to the project

EGPR is an international Academic Virtual Enterprise (AVE) with the aim to establish a stimulating learning and working environment for the students [29]. In the series of EGPR projects Budapest University of Technology and Economics (BME) takes part for five years. In 2010 the host university was the University of Ljubljana, the project assignment was provided by Bosch Siemens Hausgeräte (BSH). The topic was to "Design a handheld blender for modern urban man". In Table 1 the product concepts are shown which are referred in this research. (C10-C12 are actual products from the hand blender market, only used as references for the different measures and factors.)

Table 1 Concepts from EGPR 2010 project

 C1	 C2	 C3
 C4	 C5	 C6
 C7	 C8	 C9
 C10	 C11	 C12

The results are promising on two areas: there has been a fuzzy-based creativity evaluation carried out (with reference to the concept selection in the project used as a sample, see 6.3.), and an automated solution space generation in combination with a fuzzy-based assessment was also made (with reference to the embodiment design phase, see 6.4.).

6.3. Evaluation of the design concepts

In the early stage of the embodiment design an important task is the evaluation of the design concepts. In the blender project creativity was a highlighted factor in the evaluation procedure. The two main components, novelty and value (the latter called utility in the research) were evaluated using the fuzzy method with the use of MATLAB fuzzy toolbox.

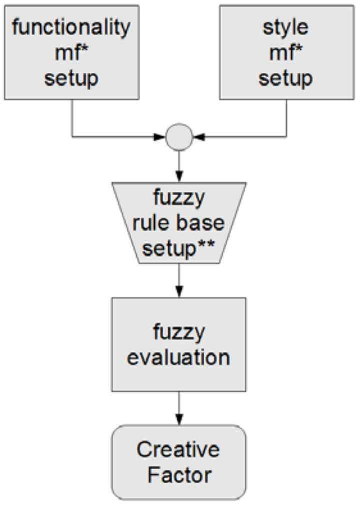


Figure 2 Scheme of the process of calculation of the Creative Factor. * fuzzy membership function; ** determined by group of experts

The scheme of the whole evaluation process is shown in Figure 2. The evaluation of novelty (referred to as style in the actual study) was based on the determination of the distance of the inspected concept from the conventional solutions, which was later transformed into a scale. In this case the measurement includes the evaluation of the appearance of the concept including the evaluation of its overall arrangement and aesthetics. On one side of the scale there are the "Conventional", on the other end there are the "Revolutionary" solutions, while in the middle the "Novel" solutions can be found. The scale runs from 1 (the conventional designs) to 10 (the revolutionary concepts). The related fuzzy membership functions are shown in Figure 3.

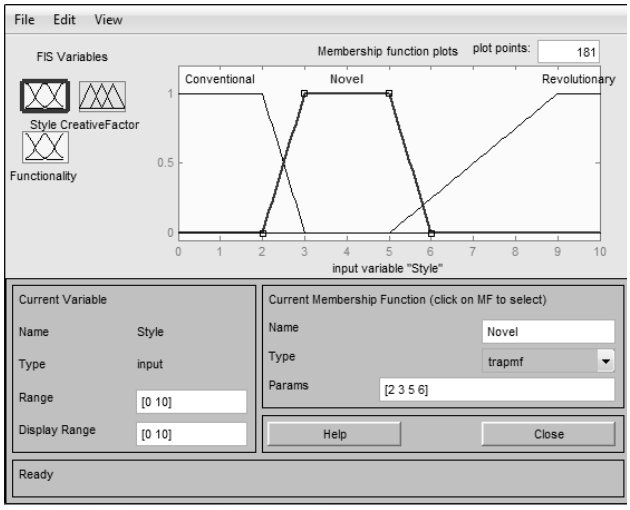


Figure 3 Fuzzy membership functions for evaluation of the concept's style.

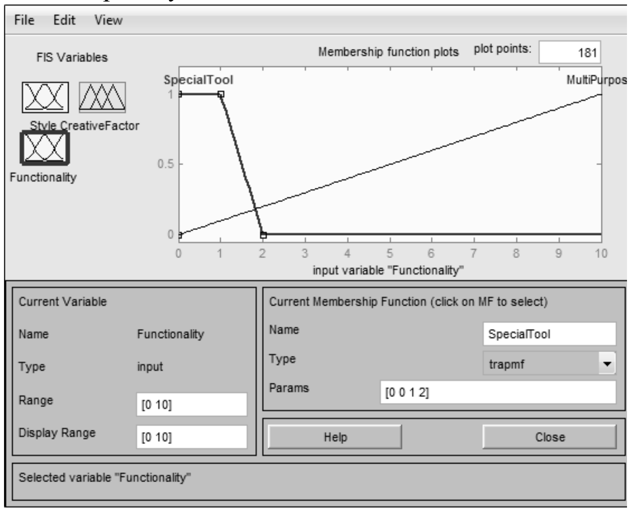


Figure 4 Fuzzy membership functions for evaluation of the concept's functionality.

The other factor of creativity is utility. In this case utility is being described with the functionality of the blender. This feature was measured also in a scale of 1 to 10. On one side of this scale the "Special Tool" was placed, on the opposite side the "Multi-Purpose" was located. (The related fuzzy membership function is displayed in Figure 4.) The output of this evaluation is the value of the "Creative Factor (CF)". This factor ranges between 1 and 10. The calculation of CF is based on the fuzzy membership functions of the "Traditional" and the "Creative" solutions (Figure 5).

The next step in the evaluation process was the definition of the rules between the input and the output membership functions. These rules have established the relationship context which made the evaluation realistic. With the use of the weight factors (Table 2) applied in the rules this realistic run-off was ensured.

Table 2 Rules for the calculation of the Creative Factor

Style		Function-ality	Weight	Creative Factor
Conven-tional	AND	Special Tool	1	Traditional (1)
Conven-tional	AND	Multi-Purpose	1	Traditional (1)
Novel	AND	Special Tool	1	Traditional
Novel	AND	Multi-Purpose	0.2	Creative (2)
Revolu-tionary	AND	Special Tool	0.1	Creative (3)
Revolu-tionary	AND	Multi-Purpose	1	Creative

The properties of the rule base:

(1) A concept with conventional style could not be a creative solution.
(2) A novel multi-purpose concept has limited creativity represented by weight factor 0.2.
(3) A revolutionary style concept can only be a partially creative solution (weight 0.1) if it is a special tool.

The validation of this rule base was done by the analysis of a number of special cases by a group of experts, as it is suggested in [30, 31].

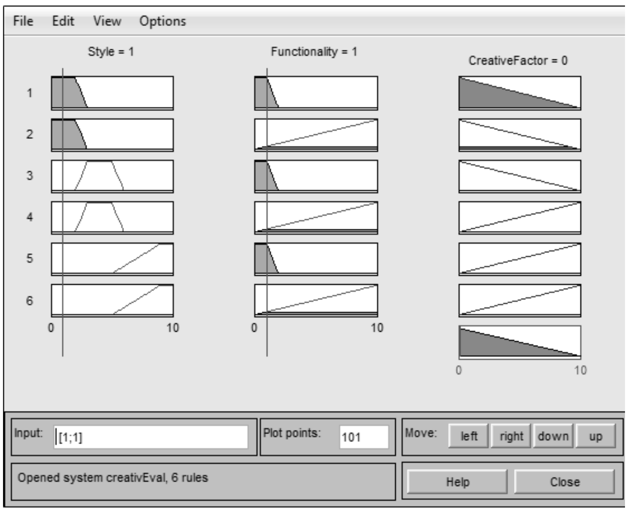


Figure 5 Validation of the fuzzy rule base. Case 1
Style=1, Functionality=1, Creative Factor=0

The case of the special tool concept in conventional style is shown on Figure 4. In this case the Creative Factor is zero.

The case of the multi-purpose concept in conventional style is shown on Figure 6. In this case the Creative Factor is also zero.

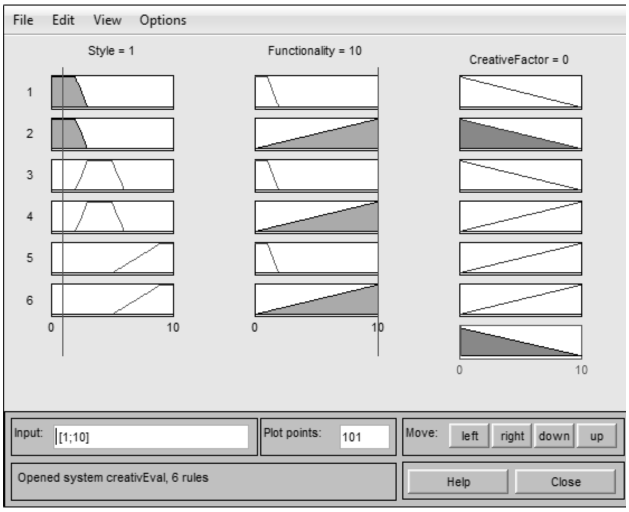


Figure 6 Validation of the fuzzy rule base. Case 2
Style=1, Functionality=10, Creative Factor=0

Figure 7 shows the case of the multi-purpose concept in novel style. In this case the Creative Factor is relatively low. Figure 8 shows the case of the special tool concept in revolutionary style. In this case the Creative Factor is also relatively low.

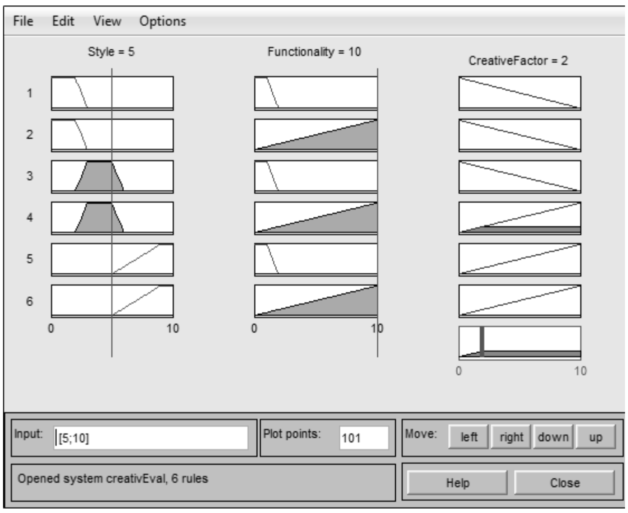


Figure 7 Validation of the fuzzy rule base. Case 3
Style=5, Functionality=10, Creative Factor=2

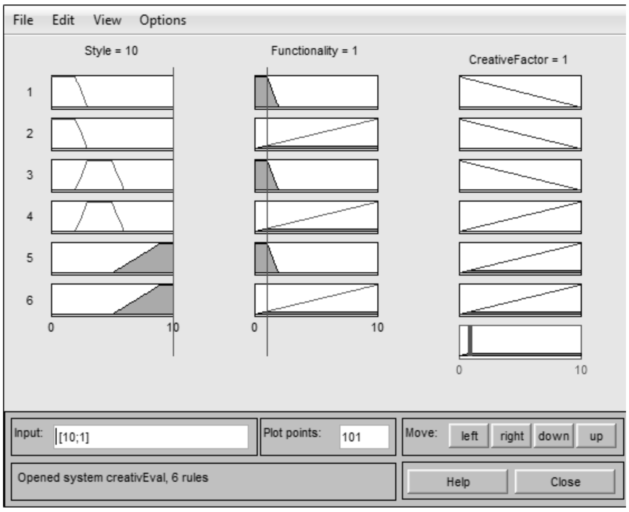


Figure 8 Validation of the fuzzy rule base. Case 4 Style=10, Functionality=1, Creative Factor=1

The post processed results of the blender project have also validated the suitability of this fuzzy inference system. Table 3 well illustrates the creative dominance of the multi-purpose appliances in revolutionary style. Opposite to this, the conventional blenders with limited functionality has low CF. The items with ID C10, C11 and C12 are real products with long time market presence. These products were involved in the evaluation procedure as a control group to test the fuzzy inference system. These low results prove the fidelity of the evaluation.

Table 3 Post processed results of the different concepts (S=Style, F=Functionality, CF=Creative Factor)

ID	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
S	9	7	9	5	8	9	8	4	5	2	2	3
F	9	6	6	5	5	5	9	6	3	4	5	4
CF	**9**	**5**	**6**	**1**	**5**	**5**	**7.5**	**1.2**	**0.6**	**0**	**0**	**0.9**

6.4. Automated generation and evaluation of the solution space

The second focus in the experiment was the embodiment phase, where the blender's drive system (drive train) was designed and evaluated. This process has been simplified to make the process easy to follow, therefore only two specific design parameters were selected with three different values. Figure 9 shows the scheme of the process of generation and evaluation of the solution space upon the Quality Factor.

In the case of blenders the drive train itself usually consists of a power source (wired or batteries), electric drive (electric motor) and a transmission (as an option).

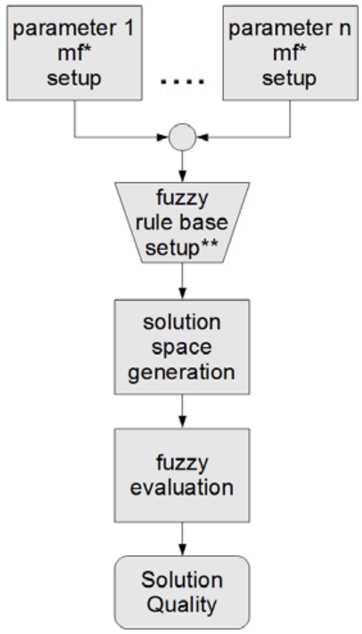


Figure 9 Scheme of the process of the calculation of the Drive Quality Factor. * fuzzy membership function;
** determined by group of experts

In this simulation the power source and the regulation of the electricity were excluded. The power of the electric motor was also neglected. Only the cooling method of the electric motor and the type of the transmission were included in this simplified process. All in all only nine type of designs can totally cover this limited (simplified) design space. Three different cooling methods were taken into consideration. The cooling types were numbered. The relationship between the ID numbers and the cooling methods are given in Table 4. The transmission of this drive train included only three elements (see Table 5).

Table 4 Legends for cooling methods

ID	Cooling method
1	Non-applied (closed system).
2	Passive cooling (open system).
3	Active cooling (with ventilator).

Table 5 Legends for transmission types

ID	Transmission type
1	Bevel gear
2	Cylindrical gear
3	Direct drive (no gear applied)

These methods have specific fuzzy membership functions in the evaluation process (Figure 10).

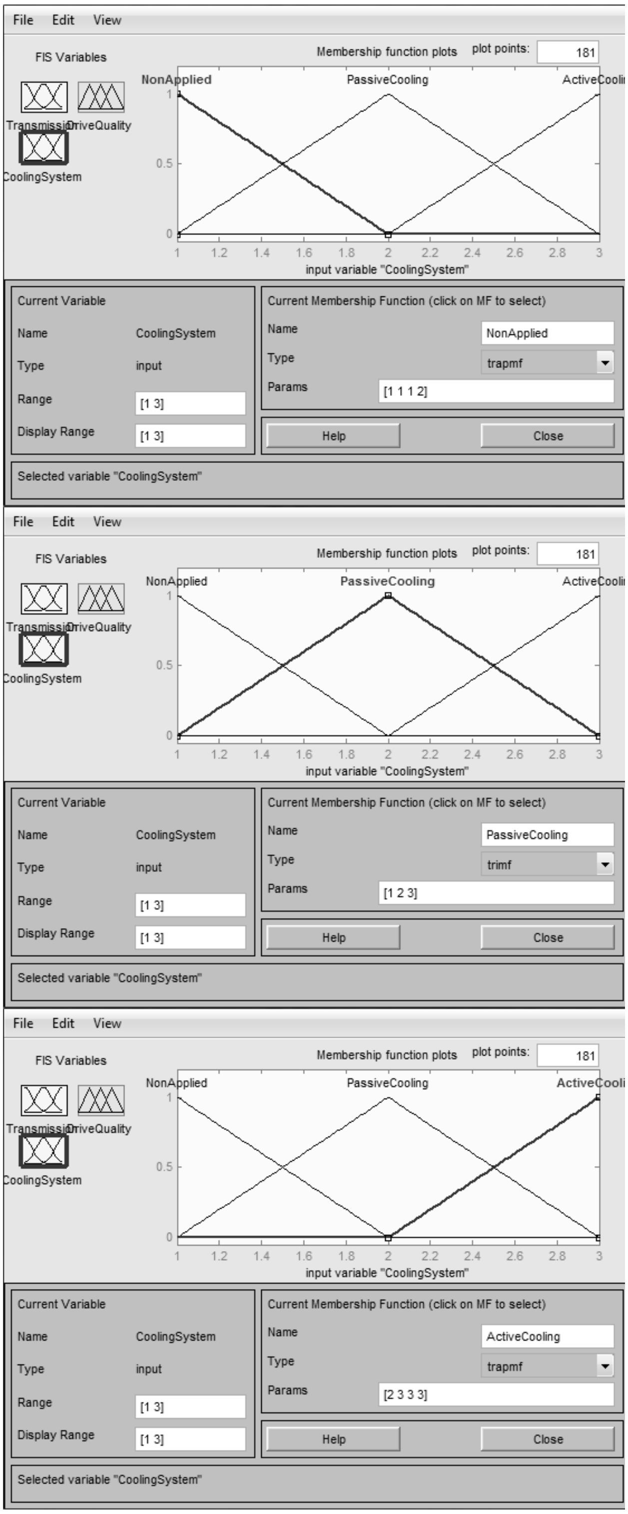


Figure 10 The fuzzy membership functions of cooling (Non-Applied, Passive Cooling, Active Cooling).

On Figure 11 the fuzzy membership functions of the different transmission methods can be seen.

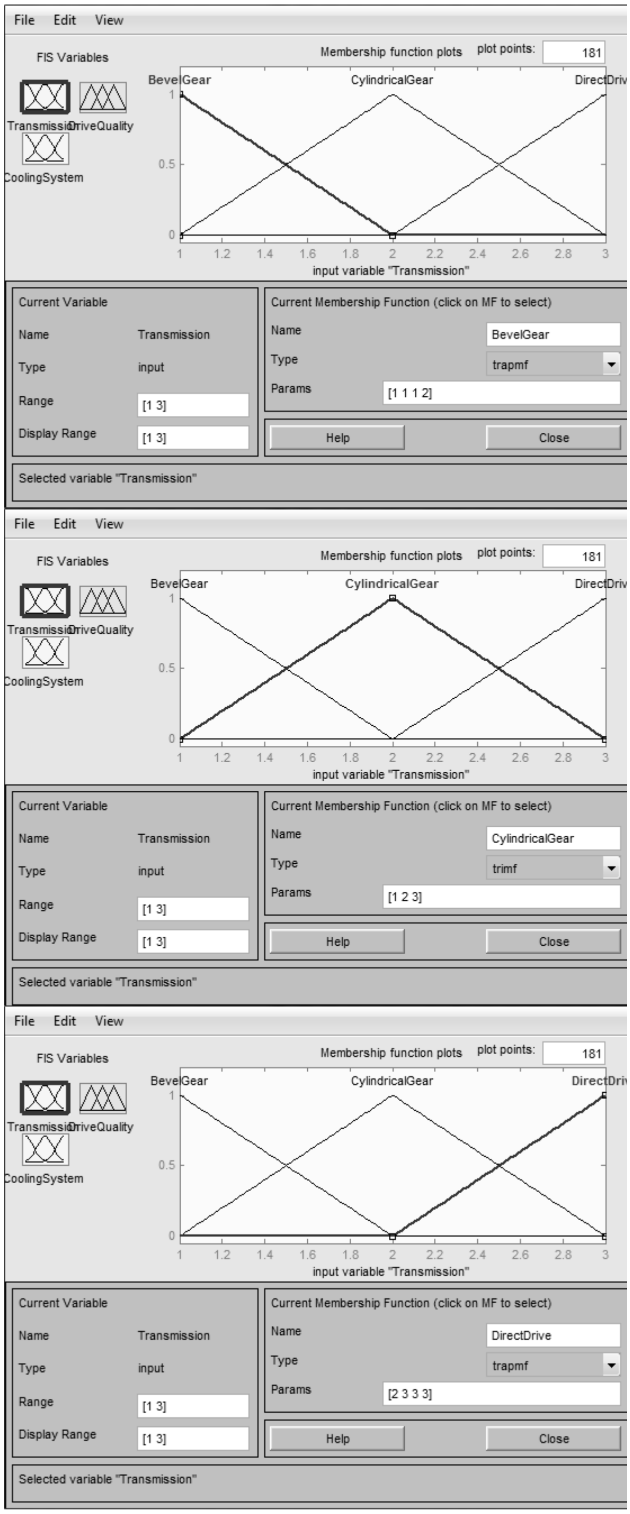


Figure 11 The fuzzy membership functions of transmissions (Bevel Gear, Cylindrical Gear, Direct Drive).

The output side of the fuzzy inference system contains two fuzzy membership functions. These functions described two opposing design aims: the long lifespan of the drive system and the quiet operation. These two requirements were considered as being contradictory with each other. The longer lifespan requires more effective cooling, which causes higher noise. The main goal of this case study was to find a well-balanced solution between these two contradictory design goals. The related fuzzy membership functions are shown in Figure 12.

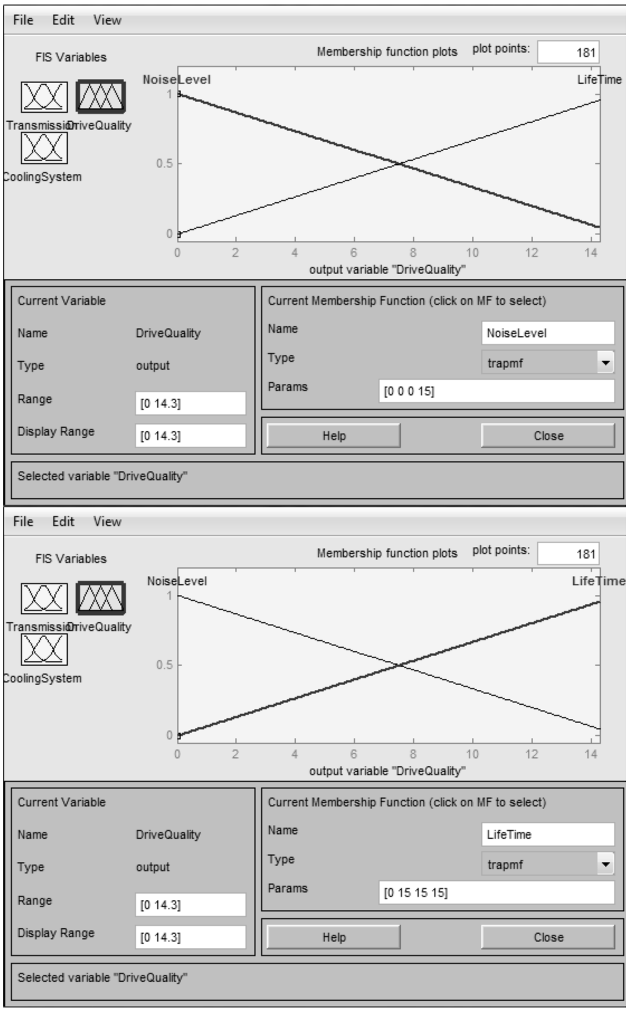


Figure 12 The fuzzy membership functions in the output side (Noise Level, Life Time).

The fuzzy rule base in this case was quite complicated to cover all the possible effects in this drive train (Figure 13). Some rules handled the noisy cases others handled the life span issues. These rules were also validated with special combinations of the cooling system and the different transmissions. After the careful validation procedure (as in 6.3.), the rule base provided realistic results from the evaluation.

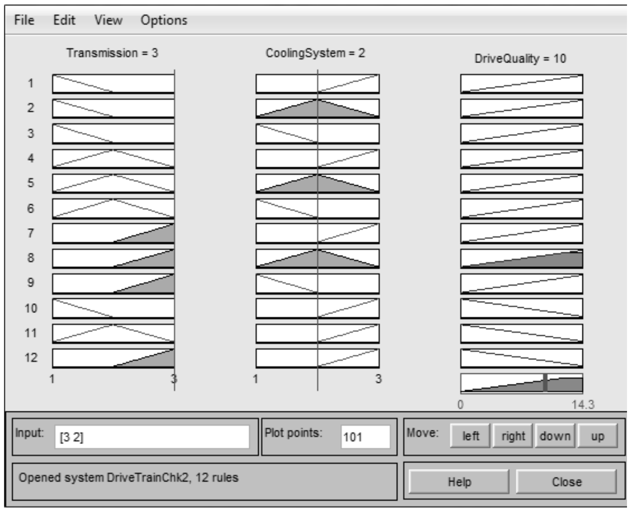


Figure 13 Fuzzy rule base for drive train evaluation

The final result of this fuzzy inference system was the Drive Quality factor. This value was calculated on a 1 to 10 scale. The higher value indicates the better balance between the noise and lifespan. The aggregated results are shown in the Figure 14.

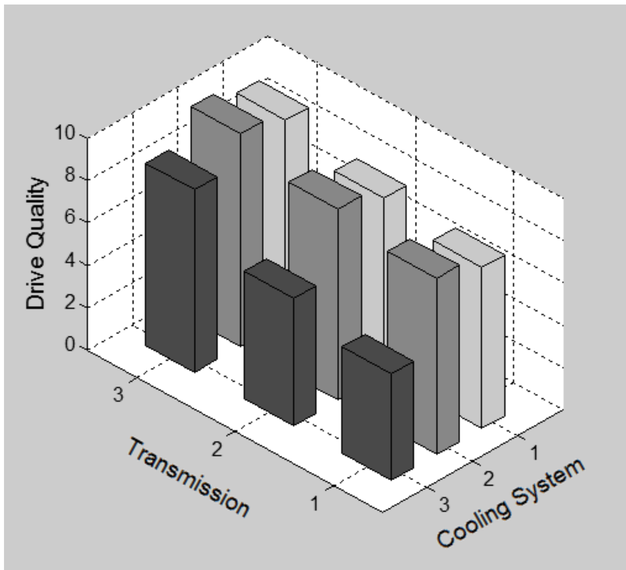


Figure 14 Results of the evaluation of the design space

The results well prove the fidelity of the fuzzy inference system. The gear based transmissions have remarkable risk to the long life time of the appliance, therefore the reference Drive Quality values are relative low. At first sight, the ideal combination is the direct drive with active cooling. Considering the final results this combination is de facto worse than the combination of direct drive with the passive cooling. It is quite reasonable from the noise issue perspective. The active cooling generates remarkable noise which decreases the quality of the drive train.

7. CONCLUSIONS

In this research the authors dealt with different possibilities to algorithmize and support the early phases of the design process from the perspective of generation and evaluation of solution variants. The paper introduced a new possible way of supporting solution generation in the early phases. The method is applicable to abstract product concepts, principle solutions and technical concepts, and could be applied also in component-level embodiment design (selection, configuration and parameter design) tasks with less dependence on human creativity.

One promising direction of the research is the early evaluation of the creative factor. On growing number of samples we will know much more about the nature of the creative thought and products. The other direction with massive possibilities is the solution generation (divergent-type) tasks, where further interesting findings are expected.

The results so far have proven the adequacy of the fuzzy applications, however authors admit that the results presented in this paper are preliminary ones, further test are necessary to validate the method.

The main advantages of this approach is the possibility of computer support, as it is relatively easy to algorithmize. As a result the fuzzy evaluation provides us with a map or an order of superiority, therefore different individual criteria or their combinations are easy to apply. There is a possibility to search an optimum, but orders could be set up in a simple way. Fuzzy logic can handle great numbers of variants, so from the design process perspective more alternatives could be kept for later screening. The applied work-flow could be adapted in computer algorithms and under some circumstances could substitute human creativity.

In the further research in this topic authors would like to focus on the support of evaluating creativity, and would like to extend and sophisticate the tool to be capable of handling associations and the surprise factor. There might be a need to develop a bespoke fuzzy evaluation algorithm.

The medium-term goal of the authors is to gather assessment data from real projects to refine the evaluation functions, and apply the method in an industrial project. The method could also be used as a tool for retrospective analysis of former projects, so the learning effect across the research could be emphasized as well.

ACKNOWLEDGMENTS

This research of Vidovics, B. underlying this paper was supported by the European Union and the State of Hungary, co-financed by the European Social Fund in the framework of TÁMOP 4.2.4. A/2-11-1-2012-0001 'National Excellence Program'.

REFERENCES

[1] Pahl, G., Beitz, W., (1995), "Engineering Design: A Systematic Approach", Springer, Heidelberg.

[2] Ullman, D. G., (1997), "The Mechanical Design Process", 4th ed., McGraw Hill, New York.

[3] Ulrich, K. T., (2011), "Design: Creation of Artifacts in Society." University of Pennsylvania, Philadelphia.

[4] Ronen, T., (2011), "The Positive Power of Imagery" John Wiley & Sons, Chichester.

[5] Stamm, B. von, (2008), "What are Innovation, Creativity, and Design?", In: Managing Innovation, Design and Creativity, Ch 1, pp. 1-17, John Wiley & Sons, Chichester.

[6] Amabile, T., (1996), "Creativity in Context", Westview Press Inc., Boulder, Colorado.

[7] Johannessen, J. A., Olsen, B., Lumpkin, G.T., (2001), "Innovation as newness: what is new, how new, and new to whom?" European Journal of Innovation Management 4 (1) pp.: 20-31, ISSN: 1460-1060.

[8] Horowitz, R., (1999), "Creative Problem Solving in Engineering Design", PhD thesis, Tel-Aviv University, Tel-Aviv.

[9] Ulrich, K. T., Eppinger, S. D., (1995), "Product Design and Development" McGraw-Hill, Singapore.

[10] Roozenburg, N. F. M., Eekels, J., (1995), „Product Design: Fundamentals and Methods", Wiley, Chichester.

[11] Runco, M. A., Pritzker, S. R., (1999), "Encyclopedia of Creativity", Academic Press, San Diego.

[12] Mumford, M. D., (2001), "Something Old, Something New: Revisiting Guilford's Conception of Creative Problem Solving"; Creativity Research Journal, 13 (3-4) pp.: 267-276.

[13] Lanjouw, J. O., Schankerman, M., (2004), "Patent Quality And Research Productivity: Measuring Innovation With Multiple Indicators"; Economic Journal, v114 (495, Apr), pp.: 441-465.

[14] Sarkar, P., Chakrabarti, A., (2011), "Assessing design creativity" Design Studies, 32 (4, July), pp.: 348-383.

[15] Brown, D. C., (2008), “Guiding Computational Design Creativity Research” 22.pp. [online]. s.l. s.n.

[16] Macedo, L., Cardoso, A., (2001), “Creativity and Surprise”; Proceedings of the AISB’01 Symposium on Creativity in Arts and Science. University of York, York. pp.: 84-92.

[17] Huang, H. Z., Bo, R., Chen, W., (2005) “An integrated computational intelligence approach to product concept generation and evaluation” Mechanisms and Machine Theory, 41, pp.: 567-583

[18] Novák, V., Perfilieva, I., Močkoř, J., (1999), “Mathematical principles of fuzzy logic”, Kluwer Academic, Dodrecht. ISBN 0-7923-8595-0

[19] Zadeh, L. A., (1965), “Fuzzy Sets Information and Control”, 8 ELSEVIER, pp.:338-353, ISSN: 0890-5401

[20] Thurston, D., Carnahan, J. V., (1992), “Fuzzy ratings and utility analysis in preliminary design evaluation of multiple attributes”, Journal of Engineering Design, 114, pp.: 648-658.

[21] Lee, D. H., Park, D., (1997),“An efficient algorithm for fuzzy weighted average”, Fuzzy Sets and Systems, 84, pp.: 39-45.

[22] Vanegas, L. V., Labib, A. V., (2001) “Application of new fuzzy-weighted average (NFWA) method to engineering design evaluation”, International Journal of Production Research, 39 (6), pp.: 1147-1162

[23] Wang, J., (2002), “improved engineering design concept selection using fuzzy sets”, International Journal of Computer Integrated Manufacturing, 15 (1), pp.: 18-27.

[24] Yan, W., Chen, C. H., Shieh, M. D., (2006), “Product concept generation and selection using sorting technique and fuzzy c-means algorithm”, Computers and Industrial Engineering, 50, pp.: 273-285.

[25] Lu, W. F., Sun, J., Loh, H. T., Chua, C. W. (2008) “Concept selection for market potential using fuzzy selection approach” Proceedings of Industrial Engineering and Engineering Management IEEE Conference, IEEE, Singapore. pp.: 1699-1703.

[26] Ivanov, J., Karabunarliev, S., Mekenyan, O., (1994), “3DGEN - A system for exhaustive 3d molecular design proceeding from molecular topology”, Journal Of Chemical Information And Computer Sciences, 34 (2) AMER CHEMICAL SOC., pp.: 234-243, ISSN: 0095-2338

[27] Firth-Clark, S., Todorov, N., Alberts, I., Williams, A., James, T., Dean, P., (2006), “Exhaustive de novo design of low-molecular-weight fragments against the ATP binding site of DNA-gyrase”; Journal Of Chemical Information And Modeling, 46 Issue: 3 AMER CHEMICAL SOC., pp.: 1168-1173, ISSN: 1549-9596.

[28] Takács Á., (2009), “Computer Aided Design Method for Concept Generation”, PhD dissertation, Miskolc University, Miskolc.

[29] Horváth I., (2006), “Design Competence Development in an Academic Virtual Enterprise”; Proceedings of IDETC/CIE 2006, ASME 2006 International Design Engineering Technical Conferences & and Computers and Information in Engineering Conference, September 10-13, 2006, Philadelphia, Pennsylvania, USA.

[30] Yan, H. B., Huynh, V. N., Murai, T., Nakamor, Y., (2008), “Kansei evaluation based on prioritized multi-attribute fuzzy target-oriented decision analysis”, Information Sciences, 178 ELSEVIER, pp.: 4080-4093, ISSN: 0020-0255.

[31] Tauhid, S., Okudan, G., (2007), “Fuzzy information axiom approach for design concept evaluation” ICED'07 28-31 August 2007, Paris, FR, p.: 573.