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IMPLEMENTATION OF ADAPTIVE PRODUCT CONFIGURATION AS AN ADDITIONAL TOOL FOR SUSTAINABLE PRODUCT LIFECYCLE

ABSTRACT:
The difficulties in implementing successful mass customization arise mainly due to uncertainty encountered by customers when they intend to customize their products - external and internal complexity - problems faced by the company because of the extensive product variety. This paper presents some results of using a developed methodology for adaptive product configuration in the field of mass customization, which deals with external complexity. The paper introduces the methodology in general and gives an overview of the particular use of the methodology that is implemented in a product configuration system for thermal insulation of buildings.

KEYWORDS:
Adaptive Configuration, Customer Profile, Product Configurator, Thermal Insulation

INTRODUCTION

In the twenty-first century, a company has to organize around the customer in order to be a successful and viable firm. Today, the marketplace is customer driven. Customers expect to get what they would like, with a side order of customization [1]. This approach raises several questions that have to be answered, one of which is that despite nowadays customers are knowledgeable in general, they are still far from being experts that can really co-create a product or a service. The role of the customer is changed, from a consumer of a product, to a partner in a process of adding value [2]. This alteration of traditional organization of a company through the involvement of the customer into the configuration of the final product faces some obvious problems. The fundamental challenge is to avoid the abortion of the configuration process by the customer. In many cases, the customer aborts the configuration process by himself. Major problem areas include the lack of a customer-desired option value regarding a specific attribute within the system as well as the inability of the customer to create definite preferences between certain option values. As a result, the customer aborts the configuration process and does not come up to the sales phase [3]. Also if customers are overwhelmed by the configuration task, there is a chance that they may abort the configuration process. Customers usually only want the product alternatives that exactly meet their requirements. If too much of a choice is offered, customers can feel frustrated or confused, and therefore incapable of making proper decisions. This overload of information is sometimes called external complexity. This external complexity is caused by the limited information processing capacity of humans, the lack of customer knowledge about the product, and customer ignorance about his or her real individual needs [4]. Based on problem analysis regarding customers' involvement in the configuration process, the main areas of investigation to be considered are the minimization of the complexity experienced by the customers [5],[6] and the reduction of the cognitive overhead, considering not only the extent of choice, but also the lack of understanding about which solution meets their needs and also the uncertainties about the behavior of the supplier and the purchasing process [7].

Outer thermal insulation of buildings is becoming more and more important, since energy resource prices have raised extensively in recent years, and environmental issues have become more relevant than ever before. Despite the widespread usage of thermal insulating materials in everyday practice, it can be noted that thermal insulation is often made self-initiated, without proper knowledge about the materials, the technology, and the calculations needed to obtain the best results. This results in inadequate solutions, that can range from high installation costs and high consumption cost to short lifetime and insufficiency of the applied insulation.

The ongoing project defines several goals for the developed configurator that can be stated as follows [8],[9]:

- *The proposed configurator has to offer web based on-line instant results;*
- *The result should be based on the latest results in research and practice;*
- *The proposed configurator should configure customized results, based on the specific characteristics of individual buildings;*
- *The proposed configurator has to minimize the potential complexity experienced by the customer, by reduction of cognitive overhead;*
- *The proposed configurator has to be used by professionals, retailers and end customers without specific technical knowledge about thermal insulation;*
- *The proposed configurator should offer an accurate enough result, which is acceptable in the research field;*
- *The configurator has to raise the awareness about the necessity and the advantages of proper thermal insulation.*

CUSTOMER PROFILE CONFIGURATION

Based on experience, the problem of adapting the process of co-creation to different customers can be solved by identification of different customer profiles that suit each individual customer's needs and limitations. To configure the appropriate customer profile a set of initial questions is asked at the beginning of the co-creation process. There is a need to analyze the answers generated by each customer and to use them to form a customer profile [10]. A number of approaches from the field of data analysis may be used, nevertheless the nature of the questions and the answers refer to the use of a non-crisp logic; therefore fuzzy logic is used to determine the appropriate customer profile [11],[12],[13]. Not only the answers are evaluated, but also the order of answering to questions. Also, during and after the process of co-creation, the customer's feedback considering his satisfaction with a configured profile is analyzed and the profile is adapted according to the feedback.

The previous version of the developed configurator that was meant to be used both by customers with average or no technical knowledge and by professionals with proper technical knowledge in the related field of investigation had some limitations, because some of the previous non-professional customers had found the product configurator too complex to use. On the other hand some of the professional customers have found that the configurator lacked the possibility of defining exact and precise input parameters. Other problems included the need for more or less accurate results, as well as more or less time-consuming configuration. These problems were solved by identification of three different customer profiles:

- *"Dummy" customer;*
- *Intermediate customer;*
- *Professional customer.*

The "Dummy" customer is a customer without proper technical knowledge about thermal insulation, or maybe a customer with no need for highly accurate results, or a customer with a need of a fast enough result, etc. The Intermediate customer is a customer with average technical knowledge about thermal insulation, but can also be a customer without proper technical knowledge about thermal insulation but with more time for completing the configuration process or with a need for more accurate result, etc. The Professional customer is a customer with proper knowledge about the problem of thermal insulation; it may also be a customer with average technical knowledge about thermal insulation but with more time for completing the configuration process or with a need for more accurate result, etc.

To configure the appropriate customer profile, three initial questions are asked before the start of the configuration process:

- *What is your estimate about your knowledge about thermal insulation?*
- *What are your needs considering the accuracy of the configuration results?*
- *How much time do you have for completing the configuration process?*

The answers can range from "I have no knowledge about thermal insulation at all" (Where the value of the answer is 0) to "I am a professional in the field of thermal insulation" (Where the value of the answer is 1) for the first question; from "I need as accurate result as possible" (Where the value of the answer is 0) to "I just want a rough estimate" (Where the value of the answer is 1) for the second question; and from "I have enough time for completing the configuration process" (Where the value of the answer is 0) to "I have limited time for completing the configuration process" (Where the value of the answer is 1) for the third question. Initially, all the answers are set to the value of 0.5. The answers are used as input data for customer profile configuration.

Based on asked questions and answers, three linguistic variables are defined:

- *Knowledge about thermal insulation (k), whose values are: very poor, poor, average, good and very good;*
- *Accuracy of the configuration results (a), whose values are: high, average, low;*
- *Time for the configuration process (t), whose values are: enough, average, not enough.*

The membership functions for the variables $\mu(x)$ are triangular or trapezoidal, and as an example, the membership function for k is shown in Figure 1. They are chosen based on previous testing and experience [14],[15], where the variables are described on the operating domain of $x=[0,1]$.

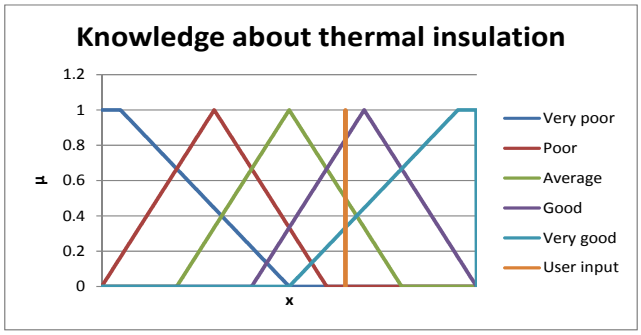

Figure 1 - Membership functions for the linguistic variable "Knowledge about thermal insulation"

Beside the values of the input variables, during the process of customer profile configuration, the order of answering the questions is also taken into consideration. The reason for doing so is that customers usually, based on their belief, sooner answer questions that are of higher importance to them than questions that are not. There is also a possibility that customers do not answer unimportant questions at all; then the value of the answer is 0.5 [16].

For the same answer values (customer input), the membership functions change, based on the answering order. If the answer to the question is the first one, the membership functions taper (1,2,3). It results in a more unique response. As an example, the membership function for k is shown in Figure 2.

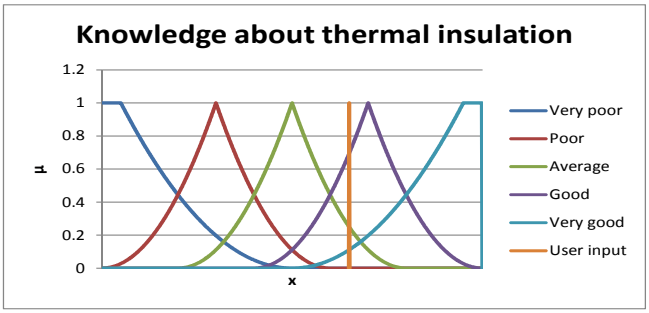

Figure 2 - Membership functions for the linguistic variable "Knowledge about thermal insulation" if it was the first answer

If the answer to the question is the last one, the membership functions expand (4,5,6). It results in a more vague response. As an example, the membership function for k is shown in Figure 3.

$$\mu_{k=very\_poor}^{1st}(x)=\left[\mu_{k=very\_poor}(x)\right]^2$$
$$\mu_{k=poor}^{1st}(x)=\left[\mu_{k=poor}(x)\right]^2$$
$$\mu_{k=average}^{1st}(x)=\left[\mu_{k=average}(x)\right]^2 \quad (1)$$
$$\mu_{k=good}^{1st}(x)=\left[\mu_{k=good}(x)\right]^2$$
$$\mu_{k=very\_good}^{1st}(x)=\left[\mu_{k=very\_good}\right]^2$$
$$\mu_{a=high}^{1st}(x)=\left[\mu_{a=high}(x)\right]^2$$
$$\mu_{a=average}^{1st}(x)=\left[\mu_{a=average}(x)\right]^2 \quad (2)$$
$$\mu_{a=poor}^{1st}(x)=\left[\mu_{a=poor}(x)\right]^2$$
$$\mu_{t=enough}^{1st}(x)=\left[\mu_{t=enough}(x)\right]^2$$
$$\mu_{t=average}^{1st}(x)=\left[\mu_{t=average}(x)\right]^2 \quad (3)$$
$$\mu_{t=not\_enough}^{1st}(x)=\left[\mu_{t=not\_enough}(x)\right]^2$$
$$\mu_{k=very\_poor}^{1st}(x)=\left[\mu_{k=very\_poor}(x)\right]^{0.9}$$
$$\mu_{k=poor}^{1st}(x)=\left[\mu_{k=poor}(x)\right]^{0.75}$$
$$\mu_{k=average}^{1st}(x)=\left[\mu_{k=average}(x)\right]^{0.25} \quad (4)$$
$$\mu_{k=good}^{1st}(x)=\left[\mu_{k=good}(x)\right]^{0.75}$$
$$\mu_{k=very\_good}^{1st}(x)=\left[\mu_{k=very\_good}\right]^{0.9}$$
$$\mu_{a=high}^{last}(x)=\left[\mu_{a=high}(x)\right]^{0.25}$$
$$\mu_{a=average}^{last}(x)=\left[\mu_{a=average}(x)\right]^{0.75} \quad (5)$$
$$\mu_{a=poor}^{last}(x)=\left[\mu_{a=poor}(x)\right]^{0.25}$$
$$\mu_{t=enough}^{last}(x)=\left[\mu_{t=enough}(x)\right]^{0.25}$$
$$\mu_{t=average}^{last}(x)=\left[\mu_{t=average}(x)\right]^{0.75} \quad (6)$$
$$\mu_{t=not\_enough}^{last}(x)=\left[\mu_{t=not\_enough}(x)\right]^{0.25}$$

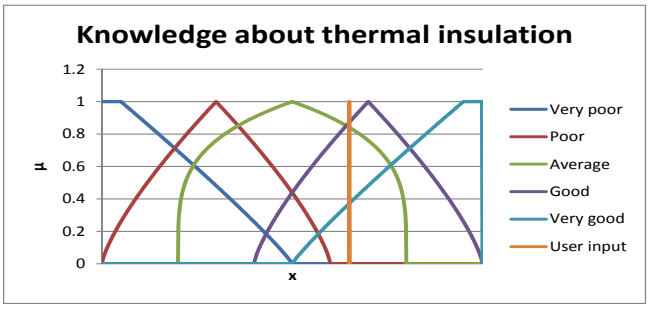

Figure 3 - Membership functions for the linguistic variable "Knowledge about thermal insulation" if it was the last answer

In Figure 1, Figure 2 and Figure 3, for the same customer input (answer) of 0.65, the membership functions are different, i.e. the values of the membership functions are also different, which is shown in Figure 4.

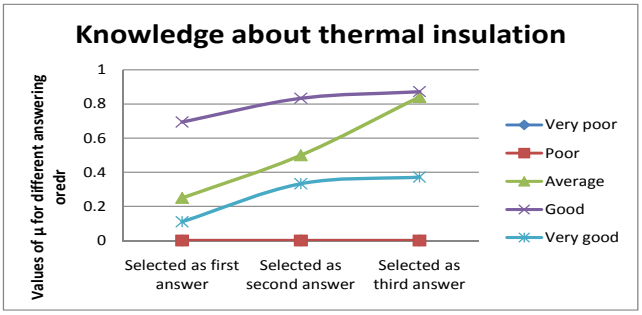

Figure 4 - Different values of the membership functions for different answering order

The fuzzy output from the system, i.e. the decision is made in a manner that 45 if-then rules are defined. The rules are designed to produce three different outputs (o): "dummy", intermediate and professional. The membership functions are triangular or trapezoidal (Figure 5), and are chosen based on previous testing and experience (7,8,9) [14],[15].

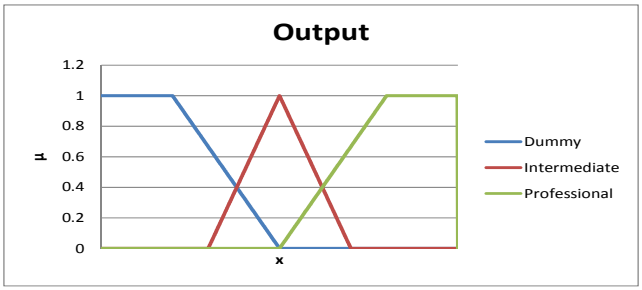

Figure 5 - Membership functions for output

$$\mu_{o=dummy}(x)=\begin{cases}1, & 0\le x\le\alpha_0\\ \dfrac{\beta_0-x}{\beta_0-\alpha_0}, & \alpha_0<x\le\beta_0\\ 0, & \beta_0<x\le 1\end{cases}, \qquad (7)$$

where $\alpha_0=0.2$, $\beta_0=0.5$ are the initial values

$$\mu_{o=intermediate}(x)=\begin{cases}0, & 0\le x\le\chi_0\\ \dfrac{x-\chi_0}{\delta_0-\chi_0}, & \chi_0<x\le\delta_0\\ \dfrac{\varepsilon_0-x}{\varepsilon_0-\delta_0}, & \delta_0<x\le\varepsilon_0\\ 0 & \varepsilon_0<x\le 1\end{cases}, \qquad (8)$$

where $\chi_0=0.3$, $\delta_0=0.5$, $\varepsilon_0=0.7$ are the initial values

$$\mu_{o=professional}(x)=\begin{cases}0, & 0\le x\le\phi_0\\ \dfrac{x-\phi_0}{\phi_0-\varphi_0}, & \phi_0<x\le\varphi_0\\ 1, & \varphi_0<x\le 1\end{cases}, \qquad (9)$$

where $\phi_0=0.5$, $\varphi_0=0.8$ are the initial values

After the evaluation of if-then rules, an aggregated output is generated. Changes in input membership functions influence the customer profile configuration. For the same answers, but for a different answering order, the configured customer profile can be different.

The next example shows that for the following input data:

- *1st answer - customer input for knowledge about thermal insulation is 0.65;*
- *2nd answer - customer input for accuracy of the configuration results is 0.8;*
- *3rd answer - customer input for time for the configuration process is 0.5,*

after defuzzification by the "Center of gravity method", the crisp output is 0.387 - and is interpreted as an "Intermediate customer".

For the following input data:

- *1st answer - customer input for accuracy of the configuration results is 0.8;*
- *2nd answer - customer input for knowledge about thermal insulation is 0.65;*
- *3rd answer - customer input for time for the configuration process is 0.5,*

after defuzzification by the same method, the crisp output is 0.369 - and is interpreted as a "Dummy customer".

Based on the previous example, one can conclude that for the same input data, but for a different answering order, different customer profiles can be configured.

After the configuration task is finished, a feedback is generated. The customer is asked to answer a set of three questions:

- *Are you satisfied with the complexity of the configurator? (c);*
- *Is the result satisfactory? (s);*
- *Are you satisfied with the time spent for the configuration process? (i).*

The answers can range from "The configurator is too complex" (where the value of the answer is 0) to "The configurator is too easy " (where the value of the answer is 1) for the first question; from "The results should be more detailed and precise " (where the value of the answer is 0) to "The results are too detailed" (where the value of the answer is 1) for the second question; and from "I could have spent more time for the configuration process" (where the value of the answer is 0) to "The configuration process was too long " (where the value of the answer is 1) for the third question. Initially, all the answers are set to the value of 0.5, which means that the customer is satisfied with the configuration process.

Based on the answers to questions, the input values for k,a,t *are modified to* k_{new},a_{new},t_{new} *(10).*

$$k_{new}=k-\frac{c-k}{2}$$
$$a_{new}=a-\frac{s-a}{2} \qquad (10)$$
$$t_{new}=t-\frac{i-t}{2}$$

This is the input for a new fuzzy output from the system, i.e. a new decision. This new output (o_{new}*) takes into consideration whether a customer is satisfied with a configured customer profile. Based on the difference between an original and a new output, the membership functions for* o_{i+1} *are shifted left or right to better articulate the customers' preferences in the future. The amount of shifting (*sa*) is calculated in the following manner (11).*

$$sa=\frac{o_i-o_{new}}{10} \qquad (11)$$

The division by 10 is used to assure that the shift is not too big. The shifted membership functions for o are (12,13,14):

$$\mu_{o=dummy}^{i+1}(x)=\begin{cases}1, & 0\le x\le\alpha_{i+1}=(\alpha_i+sa)\\ \dfrac{\beta_{i+1}-x}{\beta_{i+1}-\alpha_{i+1}}, & \alpha_{i+1}=(\alpha_i+sa)<x\le\beta_{i+1}=(\beta_i+sa)\\ 0, & \beta_{i+1}=(\beta_i+sa)<x\le 1\end{cases} \qquad (12)$$

$$\mu_{o-intermediate}^{i+1}(x)=\begin{cases}0, & 0\le x\le\chi_{i+1}=(\chi_i+sa)\\ \dfrac{x-\chi_{i+1}}{\delta_{i+1}-\chi_{i+1}}, & \chi_{i+1}=(\chi_i+sa)<x\le\delta_{i+1}=(\delta_i+sa)\\ \dfrac{\varepsilon_{i+1}-x}{\varepsilon_{i+1}-\delta_{i+1}}, & \delta_{i+1}=(\delta_i+sa)<x\le\varepsilon_{i+1}=(\varepsilon_i+sa)\\ 0 & \varepsilon_{i+1}=(\varepsilon_i+sa)<x\le 1\end{cases} \quad (13)$$

$$\mu_{o-professional}^{i+1}(x)=\begin{cases}0, & 0\le x\le\phi_{i+1}=(\phi_i+sa)\\ \dfrac{x-\phi_{i+1}}{\phi_{i+1}-\varphi_{i+1}}, & \phi_{i+1}=(\phi_i+sa)<x\le\varphi_{i+1}=(\varphi_i+sa)\\ 1, & \varphi_{i+1}=(\varphi_i+sa)<x\le 1\end{cases} \quad (14)$$

with the following corrections (15):

$$\begin{aligned}&if\ \alpha_{i+1}<0.05\ then\ \alpha_{i+1}=0.05;if\ \alpha_{i+1}>0.35\ then\ \alpha_{i+1}=0.35\\ &if\ \beta_{i+1}<0.35\ then\ \beta_{i+1}=0.35;if\ \beta_{i+1}>0.65\ then\ \beta_{i+1}=0.65\\ &if\ \chi_{i+1}<0.15\ then\ \chi_{i+1}=0.15;if\ \chi_{i+1}>0.45\ then\ \chi_{i+1}=0.45\\ &if\ \delta_{i+1}<0.35\ then\ \delta_{i+1}=0.35;if\ \delta_{i+1}>0.65\ then\ \delta_{i+1}=0.65\\ &if\ \varepsilon_{i+1}<0.55\ then\ \varepsilon_{i+1}=0.55;if\ \varepsilon_{i+1}>0.85\ then\ \varepsilon_{i+1}=0.85\\ &if\ \phi_{i+1}<0.35\ then\ \phi_{i+1}=0.35;if\ \phi_{i+1}>0.65\ then\ \phi_{i+1}=0.65\\ &if\ \varphi_{i+1}<0.65\ then\ \varphi_{i+1}=0.65;if\ \varphi_{i+1}>0.95\ then\ \varphi_{i+1}=0.95\end{aligned} \quad (15)$$

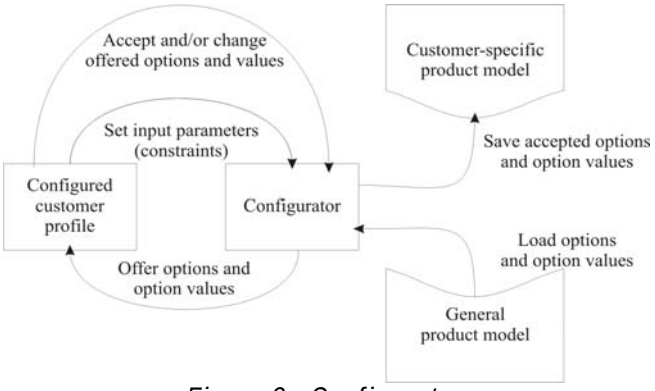

Figure 6 – Configurator

The configured customer profile is used in the configurator (Figure 6).

CASE STUDY

The developed configurator has been tested configuring five existing buildings. The insulation is configured and the results are calculated for each customer profile. Heat loss is calculated for input temperatures [14],[15]. Heat losses without insulation and with the proposed insulation, for different customer profiles are shown in Figure 7 and Figure 8, respectively.

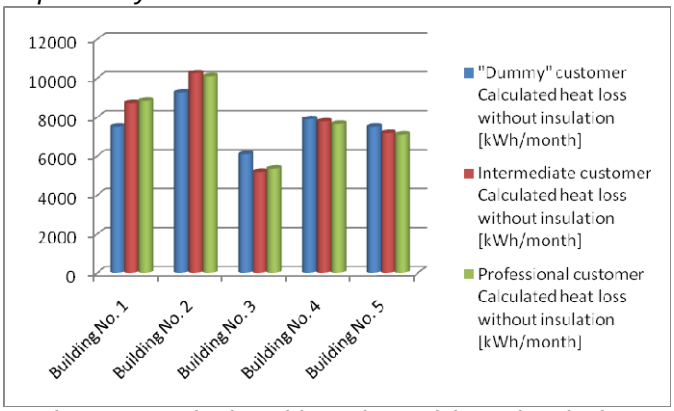

Figure 7 - Calculated heat loss without insulation

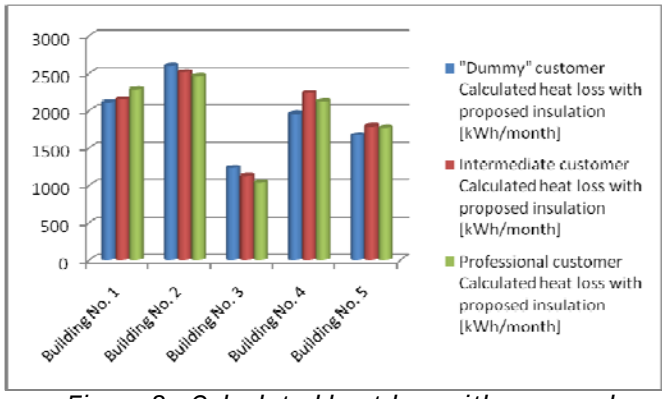

Figure 8 - Calculated heat loss with proposed insulation

CONCLUSION

The process of co-creation during the configuration task faces several problems. If customers are overwhelmed by the configuration task, or there is a lack of a desired option value for a specific attribute, or the customers simply do not understand the configuration process, they may abort the configuration process and do not come up to the sales phase.

Therefore the solution to these problems is to adapt the process of co-creation to different customers by identification of different customer profiles that suit each individual customer's needs and limitations. To configure the appropriate customer profile a set of initial questions is asked at the beginning of the co-creation process. After the answers generated by each customer are analyzed a customer profile is determined using fuzzy logic. Not only the answers are evaluated, but also the order of answering to questions. Also, during and after the process of co-creation, the customer's feedback considering his satisfaction with a configured profile is analyzed and the profile is adapted according to the feedback.

The case study shows that average deviation from the exact calculations for the "dummy" customer range from approximately 9.19% for calculations without thermal insulation to 9.31% for calculations with thermal insulation. Average deviation for the intermediate customer ranges from approximately 1.74% for calculations without thermal insulation to 4.68% for calculations with thermal insulation. Based on these results one can conclude that different customer profiles give different results, but that the differences could be accepted if the nature of the research field is taken into consideration.

The configuration process in the case of the "dummy" customer lasts about 3-4 minutes, for the intermediate customer the required time is about 5-10 minutes, and for the professional customer it takes more. The final solution is given in understandable form, which can be directly used for ordering. These results show that different customer profiles could be necessary for successful completion of the configuration process.

Experiences from retailers suggest that the idea of insulating a building is becoming more appealing and acceptable for the customers, when presented using the configurator, while end users suggest that there is further need to make the configurator more interesting.

The results and the gained experiences point towards several future research directions:

- Making the user interface more interesting by using as many visual and interactive elements as possible with real time multimedia help;
- Definition of rules for taking into account the accepted solutions by previous customers of certain profile and their incorporation into configurator;

Development of an intelligent decision making algorithm that takes into consideration the input parameters and constraints, the customer profile, the previously accepted solutions and that can automatically adjust the solution that can lead to suggested solutions, which correspond to a greater extent to the finally accepted results.

REFERENCES

[1] Galbraith, J. R: Designing the Customer-Centric Organization, Jossey-Bass, San Francisco, 2005.
[2] Reichwald, R., Seifert, S., Walcher, D. & Piller, F: Customers as part of value webs: Towards a framework for webbed customer innovation tools, Proceedings of the 37th Annual Hawaii International Conference on System Sciences, Hawaii, 2004.
[3] Hansen, T., Scheer, C., Loos, P.: Product Configurators in Electronic Commerce – Extension of the Configurator Concept - Towards Customer Recommendation, Proceedings of the 2nd Interdisciplinary World Congress on Mass Customization and Personalization (MCP), Technische Universitaet Muenchen Munich, 2003.
[4] Blecker, T., Abdelkafi, N.: Mass Customization: State-of-the-Art and Challenges. In Mass customization: challenges and solutions, 87(2006), 1-25, Springer, New York.
[5] Berger, C., Piller, F.: Customers as Co-Designers, IEE Manufacturing Engineer, 82(2003)4, 42-46.
[6] Kumiawan, S., Tseng, M., So, R.: Consumer Decision-Making Process in Mass Customization, Proceedings of the 2nd Interdisciplinary World Congress on Mass Customization and Personalization, Munich, 2003.
[7] Franke, N., Piller F.: Key Research Issues in User Interaction with Configuration toolkits in a Mass Customization System, International Journal of Technology Management, 26(2003)5/6, 578-599.
[8] Fürstner, I., & Anišić, Z.: Customized Solution for Thermal Insulation of Buildings, Proc. Twenty-seventh Scientific Electrotechnical Conference "Science in Practice", Pécs, 2009, 35-40.
[9] Fürstner, I., & Anišić, Z.: Masterplast Intelligent Product Configurator - The New Approach In Thermo Insulation Of Buildings, Proc. Int. Sci. Conf. Management of Technology – Step to Sustainable Production, Šibenik, 256-261.
[10] Arora, N., Dreze, X., Ghose, A., Hess, J. D., Iyengar, R., Jing, V., Joshi, Y., Kumar, V., Lurie, N., Neslin, S., Sajeesh, S., Su, M., Syam, N., Thomas, J., Zhang, Z. J.: Putting one-to-one marketing to work: Personalization, customization, and choice, 2009-06-30.
[11] Zimmermann, H. J.: Fuzzy set theory – and its applications. Kluwer-Nijhoff Publishing, Boston, 1998.
[12] Bojadziev, G., Bojadziev, M.: Fuzzy logic for business, finance, and management. World Scientific Publishing, Singapore, 2007.
[13] Sreekumar, Mahapatra, S. S.: A fuzzy multi-criteria decision making approach for supplier selection in supply chain management, http://www.academicjournals.org/AJBM, 2009-05-19.
[14] Fürstner, I., Anišić, Z.: Self-Adaptive Product Configurator for Thermal Insulation, Proceedings of the 10th International Symposium of Hungarian Researchers on Computational Intelligence and Informatics, Budapest, November 2009, 669-680.
[15] Fürstner, I., Anišić, Z.: Adaptive Product Configuration for Thermal Insulation of Buildings, Proceedings of the 20th International DAAAM Symposium "Intelligent Manufacturing & Automation: Theory, Practice & Education", Vienna, November 2009, 1037-1038.
[16] Chen, V.: "Listening in" method to predict consumer purchase likelihood of green cars under mass customization approach. Proceedings of 5th International Conference MCPC 2009, Helsinki, October 2009.

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