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A development approach towards user-centered front-ends for knowledge-based engineering configurators: a study within planning of robot-based automation solutions

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Abstract. Configurators are well-established strong researched expert systems due to the high popularity and gained benefits. Nevertheless, the aspects of user-centered design are rarely researched and applied during the development of configurator front-ends. However, when addressing a mass consumer market or non-experts end-users, the front-end represents the required crucial knowledge that bridges the end-user's current level of knowledge to the experts' knowledge. In order to push the application of knowledge-based engineering configurators for a mass market in SMEs, a user-centered configurator frond-end for the concept planning of robot-based automation systems is being developed within the platform project ROBOTOP. In this paper, the design of an architectural user-centered layer and a ten step development approach of user-centered front-ends are presented.

1 INTRODUCTION

The automation of production processes as well as digitalization in engineering within the framework of Industry 4.0 promises automated workflows, higher speeds and lower costs in both production and engineering. Nevertheless, system integration causes major costs of automation solutions, which makes many solutions uneconomical for small and medium-sized companies (SME). Continuous engineering with focus on simulation is mentioned in this context to reduce costs and time as well as to improve quality. [1]

1.1 Motivation and aim

Despite intensive efforts, pure simulation approaches provide limited benefits without the inclusion of expert knowledge as well structured approaches to prepare knowledge. Nevertheless, people and project specific solutions are common practice and often prevent scalability to other projects and sustainable cost reduction [2] [3]. Especially for effective and scalable knowledge reuse, knowledge-based configurators and associated methods have established themselves as a well-proven approach [4] [5].

However, the use of knowledge-based configurators is primarily established in expert and business-to-business (B2B) communities and scaling on the mass customized consumer market is still limited [6]. Reasons are routed in the development of front-ends of configurators, which are mostly not user-centered and are given low priority and development capacity. As a result, such systems are often too complex for targeted non-expert users and in some cases, users have to answer questions during configuration processes that include partly the configuration solution, rather than user-requirements. According to Steve Jobs, design is how something works [7]. A user-oriented design can therefore not be imposed on a finished solution, but should rather be an integral part of the development process [7].

The aim of the paper is therefore to show how user-centered approaches for the B2B can be used to make complex configurators accessible to a wider audience who are not business experts or non-expert customers. This is addressed by a development approach towards a user-centered engineering configurator using as an example the concept planning of robot-based automation solutions.

1.2 Structure of the paper

The paper is divided into five further sections: Firstly, the theoretical background of the scientific idea is explained, showing both the status and the challenges in the development of expert tools focusing on knowledge-based engineering configurators (KBEC), as well as benefits and solutions from the field of user-centered development. Secondly, the research method is briefly presented. Thirdly, the development approach towards user-centered front-ends for KBEC is introduced, which is divided into an architectural user-centered layer integration and the development approach. Fourthly, the use case is introduced, the implementation of the concept and method is demonstrated and validated by means of user-testing and expert discussions. Fifthly, a summary of the main findings and an outlook on further development opportunities is given.

2 THEORETICAL BACKGROUND

The following sub-sections summarize the relevant theoretical background of expert systems respectively KBEC and user-centered development, which have been mostly considered as independent fields of research. Due to the high complexity and variance of engineering tasks and the non-expert target group, a need-based interface [8] [9] is targeted instead of a parameter-based interface. The highly relevant knowledge about the voice of the customer [9] (SME) and the system integrator is addressed within the front-end.

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2.1 Situation of developing expert tools

The research of expert tools such as knowledge-based configurators (KC) is mainly focused on the modeling of expert knowledge and its implementation and integration into existing IT landscapes [5] [6] [10] [11]. The development of KC is primarily project-based, less focusing on sustainable cost-reduction for development and on cross-project knowledge elements reuse [12].

One reason for the expensive developments is that most configurators are single project or product configurators [12] and are developed based on a given fixed product structure and less for dynamic, general planning tasks based on generalized knowledge. As a result, the user domain is often too small to justify developments that are more extensive.

One solution to reduce the development costs for configurators is a cross-project reuse of partial results of configuration projects. Schäffer et al. [13] present a collaborative and work-sharing development process for knowledge-based engineering configurators (KBEC) considering a cross-project reuse using the example of the collaborative configuration model development for engineering configurators based on eight-step model.

2.2 Complication of KBEC

Another limitation to the potential mass utilization of expert tools focusing on KBEC is the requirement of professional knowledge which makes them difficult to understand and use by non-experts [9] [14] [15]. Consequently, the potential target audience is limited which in quintessence also limits the available budget for development. Since no knowledge elements can be imported from previous projects for technical or contractual reasons [16], they have to develop the configurator from scratch each time. Therefore, each part of the configurator can only be developed to a limited extent within the economic limits, and learning effects cannot be accumulated over time. Consequently, only one front-end view beneath the available possibilities is developed for a specific configurator project which also limits the potential target audience [9].

Apart from budgetary limitations of KBEC, there is often no awareness of customer needs [9] with respect to user-centered design (UCD) approaches and their benefits within configuration projects; especially as front-end development is frequently presented as a secondary sideline activity. Therefore, UCD is briefly introduced. The goal is to make existing and new configurators accessible to a wider audience.

2.3 User-centered design

User-centered design (UCD) offers numerous advantages and frequently mentioned benefits are: Increased customer satisfaction (33 %), improved usability (20 %), increased revenue (19 %) and reduced customer support costs for the software (18 %) [17] .

Usability is the level to which a solution can be used by a specific user group in a concrete user context to achieve a defined goal. The degree of usability fulfillment can be divided into three levels: (1) effectiveness, (2) efficiency and (3) user satisfaction, see Figure 1. The first one focuses on precision and the degree of task fulfillment. The second one highlights the users' necessary competence, the required time for usage and therefore the cost-efficiency e.g. [18] for task fulfillment. The third stage focuses on the system level of user acceptance and user friendly interface, and therefore on the satisfaction of the users [6]. [19] [20]

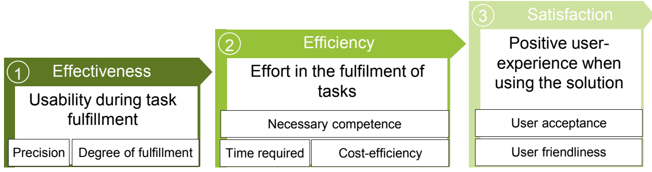

Figure 1. The three stages of the usability; from effectiveness to user satisfaction [19] [20]

One of the central lessons from the UCD according to Nielsen [21] is, that the developer is not the typical user and therefore it is essential to involve targeted user groups in the development process. In addition, the Standish Group estimates that 50 percent of all software functions remain unused or are rarely used [22]. Complexity is not only a "creator"-problem, but also a "user and consumer"-problem. By involving users in the development process, there is enormous potential for complexity reduction, both for the development team and the users. The UCD approach also fits well within modern microservice [23] and micro-frontend architectures [24] [25].

It is therefore important to observe end-users and to involve them in the development process within frequent and regular feedback cycles, e.g. in the form of a mock-up, i.e. a scale model for presenting overall impression, or a click-prototype, i.e. a partially interactive demonstrator of a user interface that simulates certain interactions. Concept decisions should be made based on statistical data. Therefore, concepts and prototypes are used as tools for the validation of hypotheses of the development team [20] [21] [26].

3 RESEARCH METHODOLOGY

The research methodology is a front-end study approach which can be summarized as an architecture and development approach empowered by proof of concept test-design (user-centered front-end of KBEC). The study is based on a single use case which focuses on the concept planning of robot-based automation solutions (ROBOTOP) [27]. The study addresses a typical problem of system integrators distributing automation solutions to SMEs, analysing the automation potential, informing SMEs, finding a first conceptual solution for the contract and keeping the sales costs low at the same time [3]. In particular, since SMEs which acquire an initial automation solution also have a high demand for knowledge. To validate this approach user-testing as well as expert interviews are performed. The final prototype was presented to and discussed with experts from the field of sales of robot-based automation solutions and configuration development.

4 APPROACH TOWARDS USER-CENTERED FRONT-ENDS FOR KBEC

The fourth chapter is divided into two parts, the general architectural classification of user-centered configurators and the development concept of user-centered front-ends for configurators.

4.1 Architectural user-centered layer

Configurators established in the consumer and B2B market focus on the advisory salesperson, which manually translates the logical structure to the end-user. Therefore, a top layer should be introduced as a surface of a pure one-to-one parameter input configurator, which translates the vague requirements of the customer into concrete parameters and solutions similar to advice from an expert salesperson. This layer serves metaphorically as a digital bridge between the non-expert-user-groups and the expert knowledge integrated inside the logical configuration model, see Figure 2.

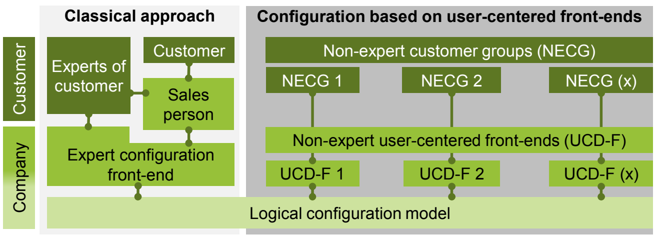

Figure 2. Comparison between classic configuration architecture with user-centered configuration architecture

In order to integrate the specific understanding, a user-centered front-end development approach for knowledge-based configurators will be introduced and presented for one specific user group within concept planning of robot-based automation solutions for SMEs.

4.2 Development approach of user-centered front-ends

The development concept is divided into three main phases consisting of ten sub-steps. The range of functions for first user-centered KBEC was deliberately limited because technical complexity would otherwise be too extensive. Therefore, the concept of a minimal viable prototype was applied. In addition, an important concept for the user-centered KBEC is that the users are only asked questions that can be answered within their knowledge domain concerning product and production process (user-requirements). The general classification into product, process and resource is known as PPR-model, introduced by Steinwasser [28]. Questions concerning the technical design of the resource (configuration solution) especially the automation solution will not be raised. Therefore, the "Best Practice"-based-configuration-approach is developed whereby a "Best Practice" is a successful realized automation solution from past engineering projects needed for initial starting points [9] or default configuration parameters [29] [30]. Parallelly, the configuration model was developed and described by Schäffer et. al. [13]. For the sake of simplicity, the concept is based on the assumption, that a logical configuration model is simultaneously developed and the Best Practices are already available. The approach is based on the general user-centered approach and has been extended and concretized within the scope of the configuration project [31]:

I) Preparation:

1. Defining the strategic objective of the configuration project based on major economic or social challenges.
2. Selecting the business case and target group, whereby the size of the target group as well as economic market demands are taken into account.
3. Analyzing the current situation and processes of the selected business case and target group based on literature review and expert interviews.

II) Initialization:

4. Concept workshop to present of the current situation and discuss with various stakeholders from management, sales, engineering, marketing and customers. Using flipcharts, whiteboards and a moderator's toolbox, first concepts can be initialized.
5. First concept design sequence is created using a graphical program or presentation tools e.g. PowerPoint.
6. Qualitative feedback, based on the individuals of the first concept workshop to improve the concept design.
7. Click-prototype based on the improved concept design via rapid prototyping tool e.g. Axure (www.axure.com) or balsamiq (www.balsamiq.com) in combination with a CAD environment e.g. Inventor (www.autodesk.de/products/inventor) to create the 3D-scenes of the Best Practices.

III) User-centered optimization:

8. User-testing and optimization based on the click-prototype, with iterative cyclic optimizations.
9. The first milestone achievement when the click-prototype contains all essential functions and contradictory user feedback is given. Then the first prototype can be released for the platform or live system to be integrated.
10. Multi-user-testing and optimization within online platform or live system and also further development of click-prototypes for the purpose of easy testing of new ideas.

5 REALIZATION AND VALIDATION

As a result of applying the approach, a front-end for the rough concept planning of robot-based automation solutions was created and the process was validated. For a better understanding, the developed use case and goal is firstly described (preparation). The strategic objective as well as the business case and target group selection (see chapter 5.1) was based on the PAiCE project call of the German Federal Ministry of Economic Affairs and Energy (BMWi) [32]. Secondly, the results are presented, as well as the main findings resulting from the user-centered development process. Finally, the development process and the results are evaluated based on user-tests and expert discussions.

5.1 Use case: concept planning of robot-based automation solutions

The target group of the user-centered configurator example are small and medium-sized manufacturing companies (SME) that have expertise in a specific product and its manufacturing process, but not within automation solutions. Typically, manual production with increasing production quantities are the starting point for further automation. In order to realize a turnkey automation solution, SMEs usually contract a system integrator. Nevertheless, many SMEs are non-lucrative customers, having a low automation-knowledge-level which leads to high consultative effort for sales as well as having smaller budgets compared to companies e.g. automotive OEMs or large tier-1 suppliers. Therefore, many automation solutions are not realized due to economical reasons or insufficient knowledge about their benefits. Additionally, there is the lack of planning tools, for the early basic concept planning. Configurators in general are suitable, but a complete user input of required parameters would be far too complex and time-consuming for non-experts, especially since in this phase there is a high degree of planning uncertainty.

Therefore the goal of the user-centered KBEC ROBOTOP is to support the idea generation phase for SMEs, whereby the result is a first concept that can be handed over to a system integrator for further engineering, see Figure 3. Based on the recommendation of Industry 4.0, the XML-based, open format AutomationML [33] was selected to transfer the final configuration results to system integrators. Therefore, we described the work-sharing building of data models as well as first implementations. [34]

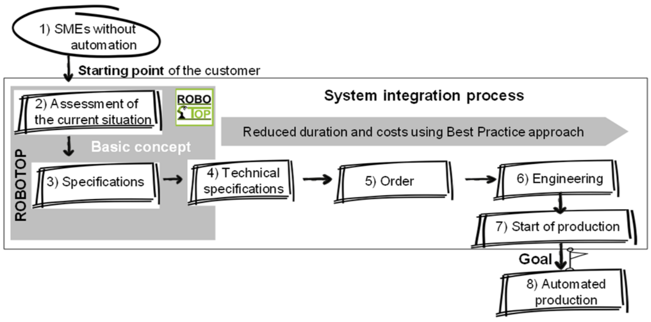

Figure 3. Scope of the user-centered KBEC for basic planning of robot based automation-solutions along the system integration process [35]

5.2 Exemplary implementation

To explain the method, essential results along the implemented validated click-prototype (in the next sections called prototype) are presented. The implementation presented in the following can be viewed as a video sequence in German at the following source [35]. As the prototype was originally developed for the German market, it has been translated within this paper into English for the sake of better communication. The result is based on more than 50 feedback loops with SMEs, system integrators and engineering experts. The prototype was incremental optimized in terms of understandability (less user comprehension questions), simplicity (as little user input as possible) and minimal completeness (only relevant information for concept planning).

1) Initial requirement entering for Best Practice filtering: Therefore, in the first step general user-requirements of SMEs such as production process description and product specifications are utilized for further Best Practice filtering in step two, see Figure 4.

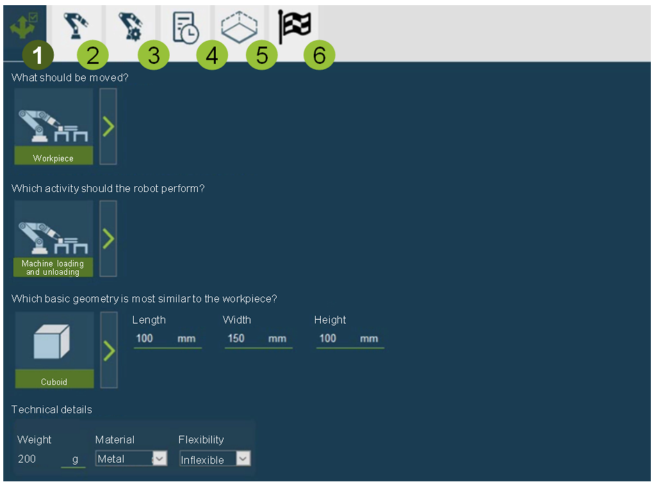

Figure 4. General condition-parameter entering (1) for Best Practice selection in the next step (2) [35]

2) Best Practice selection: The selected Best Practice serves as a starting-solution and parameter-set for the further customized configuration in step three to five. The Best Practices were conceived and condensed on the basis of a literature search, previous projects and expert discussions. The acquisition of Best Practice takes place within the scope of the ROBOTOP platform and is available to all SMEs in a consolidated database.

Based on the previous entered filtering criteria, suitable Best Practices are displayed, from which the user can select based on various qualitative evaluations such as primary advantage, cycle time, price and customer rating. Parameters for which concrete values were not available, such as price, were abstracted using rough price ranges see Figure 5, e.g. from (€€€ - €€€€) thus medium (€€€) to higher prices (€€€€).

Figure 5. Best Practice selection as initial starting point [35]

3 - 5) Customization configuration: Based on the selected and pre-loaded Best Practice parameter setup, the SME customizes the initial solution to fit most of the individual needs. The advantage of the Best Practice configuration approach is that a complete solution can be displayed as 3D-visualization right from the start, see Figure 6. This approach is therefore very user-friendly, as it provides direct and easy solution to understand the feedback. Special care was taken to ensure that the parameters with the highest technical dependencies are asked in the first phases of the user interaction with regard to changes to the overall concept.

Figure 6. Adaptation configuration (left) with 3D-visualisation (right) [35]

More complex and technically irrelevant questions are initially filled with the Best Practice-parameters. These are partially individualized in the course of steps three to five. The process parameters, such as supply and delivery condition as well as needed cycle time are individualized. Subsequently, additional basic conditions are included, such as space restrictions, desired autonomy time, protection class and data connection. By entering the shift information of the previous, manual production, the required cycle times and from these the economic potential of the automation solution can be calculated.

6) Summary and contact establishment: Lastly, the main results of the configuration are summarized. Based on request, the configuration, contact data and other requirements will be forwarded to a system integrator respectively contractor who can support the further engineering process.

5.3 Validation through user-testing

The prototype was cyclically tested and further developed along with the user-centered development process using an HTML-prototype developed within the rapid prototyping environment Axure. The configurator was evaluated for comprehensibility testing the potential SME customers and with the system integrators to ensure the technical completeness and inclusion of relevant information. This fact that the configurator requires only a few simple queries, leads us to a predefined process. The generated displays of an initial 3D-concept based on Best Practices from step three was rated positively by the users. In general, the user-centered approach was evaluated positively, even though only conceptual and technical information could be provided, since e.g. commercial information such as prices are very customer-specific. Therefore, commercial information is not provided online by system integrators and components manufacturers.

5.4 Validation through expert discussion

Furthermore, the final prototype was presented to and discussed with several experts from the field of sales of robot-based automation solutions and configuration development. The general requirement for a tool for the preliminary concept planning could be confirmed. However, sales staff in particular were sometimes sceptical about the concept, maybe because they consider their position to be endangered by such tools. The approach to develop a configuration front-end by click-prototypes via Axure was new for all experts but was considered very promising. In some cases, the cost of creating individual front-ends for different target groups was considered too high. Moreover, cost-reducing methods and therefore research projects were classified as very reasonable.

6 CONCLUSION AND OUTLOOK

In this paper, we introduced an approach for user-centered front-ends for knowledge-based engineering configurators (KBEC), considering the PPR-model (product, process and resource) from engineering. Hence we introduced the idea of an architectural user-centered layer and a ten step development approach of user-centered front-ends. Therefore, we designed and implemented an exemplary user-centered front-end within concept planning of robot-based automation solutions. The user-centered frond end is developed in parallel to the configuration logic. This serves both to clarify the requirements and to narrow down the required logic. For the implementation of a user-centered front-end, possible example software tools were identified. The steps 1-6 of the user-centered front-end could also be transferred as a general pattern to further configuration of engineering tasks. A first fusion of configuration development and user-centered approaches with focus on the front-end were shown, requiring consideration in the future projects.

As a next step, the prototypes can be analytically evaluated and optimized based on a larger number of test users. Tools to record and analytically evaluate the click-path and termination-rates of users from websites or HTML prototypes can be used, e.g. Open Web Analytics or Google Analytics. Various links to different variants of the prototype can also be distributed to specific target groups. This enables a successive further development of the configuration front-ends. Also a connection of user-centered front-end development with executable process models based on BPMN and the Process-driven approach [36], could be a promising combination for dynamic process integration within configurators.

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