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Product-Service Systems across Life Cycle

Virtual Modeling for Lifecycle Performance Assessment in aerospace design

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Abstract

The aim of the paper is to present an approach for the multidisciplinary evaluation of alternative modular concepts in preliminary design with the intent of enhancing engineers' capability to simulate alternative scenarios with different design configurations, so to derive decisions about the most valuable design concepts to further develop. The research contribution is novel in the way that it expands the Set-Based-Engineering approach by addressing the "servitization" challenge in two ways: firstly by the use of value models and sustainability models as decision making support, making possible a preliminary assessment of the value contribution and of the sustainability performances of a design concept; secondly, by the use of functional modelling modules and configurable systems elements for platform-based design, to manage the complex relationships within and between parts of the platform throughout the lifecycle. The paper presents the main features of the approach and introduces an industrial case concerning the development of a module component for an aircraft engine in which the approach is applied for demonstration. The paper finally elaborates on the benefits and implications of the approach in the design process.

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Keywords: model-based design; simulation; platform-based design; value.

1. Introduction

The use of computer-based simulations in product development is nowadays an established practice. The heavily increased computational potential allows manufacturers to model and simulate future products using increasingly sophisticated models of both products and processes. Simulation models cover a large spectrum of design challenges and scenarios: models are used to simulate mechanical properties, manufacturing processes and production flows and as a basis for assessing the impact of a concept in terms of quality, time and cost. All such simulation techniques if applied in parallel allow to analyze a broad range of design alternatives which are systematically narrowed down by eliminating undesirable solutions [1]. This approach to the development of a product is referred in literature as Set-Based Concurrent Engineering [2].

At the same time business models such as revenue sharing agreements, product service systems (PSS) offers [3] and warranty programs, also driven by the pressing environmental challenges, are slowly but constantly changing the way companies approach product development [4][5]. "Servitization" [6] and sustainability challenges are asking engineers to design products fulfilling environmental and lifecycle related needs, causing a perspective shift in engineers' technical horizon. Computer-based simulations however focus more on the estimation of product performances and manufacturing capabilities, rather than in simulating the lifecycle impact of a combined product – service offer [7]. The reason for this is the difficulty to quantify, and thus simulate, service-related information that owns uncertainty and immaturity, especially in the early phases of design [8].

This limitation renders a situation in which early design decisions are supported by simulation models that deliver very

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limited information about product lifecycle and service performances. In a set based concurrent engineering context, such lifecycle and service related information should therefore be integrated to strive for efficiency and effectiveness in the early design stages. This is today particularly relevant in complex development contexts, such as in the case of aerospace product development, where the efficient design and integration of highly technological components on a system is a must of any development project [5]. Here sub-systems and component manufacturers need to operate at a high level of complexity, trading off the engineering performances with cost, time, waste and the lifecycle value generated in service and operation.

The paper proposes an approach for set-based concurrent engineering addressing the "servitization" challenge. The approach is based on the multidisciplinary evaluation of alternative modular design concepts with the intent of enhancing engineers' capability to simulate alternative scenarios with different design configurations. The "servitization" challenge is addressed in two ways: first by the use of value models as decision making support, enabling a preliminary assessment of the value contribution of a design concept; second, by the use of functional modeling modules and configurable systems elements for platform-based design, to manage the complex relationships within and between parts of the platform throughout the lifecycle.

The paper presents the main features and the logic of the approach and introduces an industrial case concerning the development of a module component for an aircraft engine where the approach is applied for demonstration. The paper finally elaborates on the benefits and implications of the approach in the design process.

2. Research Approach

Participatory action research (PAR)[9] is the approach at the basis of the work presented in this paper. PAR was selected for a number of reasons. Firstly PAR involves the direct participation of both researchers and practitioners in the research design and development, and the involvement of industrial practitioners played a key role for the identification of the industrial problem to be addressed, or, in other words, for the identification of what "needed to be changed" [9]. Secondly because the research effort had both the scientific goal of building knowledge and of solving more practical industrial-related problems with important theoretical implications [9][10]. Thirdly, because PAR allows the development of the knowledge of participants so that they can act as agents of major changes in their organization [11]. Given the focus of the research, i.e. of developing an approach for demonstration, this last point was perceived as a necessary quality of the research approach to promote the final real-world application of the results.

Both data collection and problem definition have been run in collaboration between two academic institutions and one sub-system manufacturer operating in the aerospace business. Data analysis has been run in the light of the current literature on set-based concurrent engineering and on value analysis method for early design. The validity, the rationale and the logic of the approach have been verified and refined through a number of workshops and interviews run in collaboration with the industrial partner. In such occasions a wide number of individuals took part to the PAR initiative. Among those the closest collaborations were established with: a senior company specialist in product development, an expert and developer of knowledge-based systems, industrial experts in platform development and industrial experts in engine systems integration. The applicability of the approach is under verification in a real life demonstrator based on a new concept at the partner company. In the next step of the research the demonstrator will also serve as a reference to validate the effectiveness of the approach and its effect on the design process.

3. The industrial challenge: the "servitization" of value in aerospace development

To be able to run a sustainable business, industrial organizations need to assess their value proposition, which business parts are vulnerable, and what is at the core of the offer that generates value to the customer [12]. Such analysis shall influence all the decisions of a company starting from the way new products and services are designed and developed. Literature highlights that when working in the early design stages, engineers find themselves in the situation of making decisions that will radically impact the value of a future product from a variety of perspectives [36]. The identification of how valuable is a design concept is not straightforward since a wide set of variables and parameters play a relevant role [13]. Different methods in literature support the identification of value in the presence of complex design contexts, among those, Value Engineering [14], TradeSpace exploration [15], and Value Driven Design (VDD) [16], aim to introduce a more value-oriented approach to the design of complex systems.

Research shows that in aerospace component design, preliminary design decisions are strongly driven by requirements fulfilment [5]. Criteria such as high/low cycle fatigue, limit/ultimate load capability, hail ingestion, strength and stiffness, corrosion, oxidation and creep are examples of the evaluation variables of a specific concepts. Shifting toward a servitization perspective, the mere fulfilment of requirements creates a limitation in the fact that potentially valuable solutions tend to be neglected because the focus on technical, requirement-derived, performances, does not allow the designers to understand the value of a solution in a lifecycle and service perspective at system level [17]. Research in system engineering [18] has provided different indications about how the value of a new product shall be determined. Among those contributions authors have identified an important value driver in the capability of maintaining or improving the system functions in the presence of changes [19], and in evaluating system robustness under changing process conditions [15]. In addition, Steiner and Harmon [20] have proposed an extended model of value, adding a new layer of "intangibles" associated with knowledge, emotion and experience. However, the integration of such findings in model-based decision support systems has