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Integrated Product and Production Engineering Approach – A Tool-Based Method for a Holistic Sustainable Design, Process and Material Selection

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Abstract

Nowadays, new product developments often pursue different goals. In this way, for example, modern engineering systems should commonly be developed in terms of innovative (lightweight) designs and, at the same time, offer a wide range of environmental as well as economic advantages across the whole product lifecycle (PLC). Accordingly, selecting the most beneficial functional principles, processes and materials within a given product structure, if any, and based on multiple criteria is a highly complex process. Therefore, and even due to the strong interdependencies between the engineering disciplines and the individual objectives, a 'true' holistic and integrated sustainable selection of the actual (functional) design, manufacturing and material aspect is inevitable.
Concerning this matter, a stand-alone software tool in terms of a set-based method is developed which supports the engineer by screening potential combinations of functional principles, manufacturing processes and materials regarding multidimensional, i.e. ecological, economic and technical, data to address this issue.

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Keywords: Integrated Product and Production Engineering (IPPE), Sustainability, Energy-Efficiency, Material Selection, Tool-Based Method

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1. Introduction and Motivation

Over the last decades, environmental impacts of products, i.e. the material and energy consumption throughout the product lifecycle (PLC), have achieved an ever increasing attention, especially in light of the omnipresent and already widely discussed topic of climate change. Against this background, the 'sustainable development' has been defined in many ways since the concept of sustainability had appeared in the 1970s and was widely disseminated in the 1980s, amongst others, by the commonly referred and most frequently quoted Brundtland Commission [1]. Thus, an environmental protection and conservation of natural resources under a stable economic growth is prospectively targeted at the product development process.

As a result, and according to this overarching goal to balance the economic, environmental (i.e. ecological) and social (in order to technical issues) needs, allowing prosperity for the present and future generations, an integrated approach is developed to support the highly complex and interacting process selecting the most beneficial functional principles, manufacturing processes and materials, whilst particularly avoiding the over consumption of key natural resources. Accordingly, in a first step (section 2), the literature in the field of material and process selection is investigated along with appropriate state-of-the-art approaches regarding an integrated and holistic selection methodology within the product development process. Right after, the Integrated Product and Production Engineering (IPPE) approach is stated with its definition and classification of the individual development phases in section 3. Based on this, and to successfully deal with the vast complexity, a set-based software tool is presented with regard to more sustainable products in section 4. Finally, by giving a discussion and outlook in the end (section 5), the presented tool-based method is critically being reviewed.

2. State of the Art

The following section reviews relevant contributions correlated to this research. Initially, literature in the field of material and process selection is being analyzed, followed by approaches for selecting solutions within the product development process. Afterwards, existing approaches for an integrated development are evaluated.

2.1. Material and Process Selection

Selecting suitable materials within the development process of diverse technical product systems is a huge challenge for engineers, especially due to the nowadays enormous number of potential materials and their combinations. An internationally well-known and recognized method to support this decision process is described, amongst others, by Ashby [2]. The systematic selection process starts with the translation of material-related design requirements into specific material properties. Based on these properties, the whole material variety is screened by using constraints and material indices that state the ratio between two particular material properties (for example stiffness/density). Herein, the Cambridge Engineering Selector (CES) [3] supports the user during the screening process by eliminating materials which fail to perform and detecting the screened materials performing best according to the individual ranking objectives. Finally, the appropriate material selection is completed by seeking detailed information, e.g. corrosion resistance or processability with different adjacent materials. On this basis, Ashby et al. [4, 5] extend this approach by integrating process aspects. In doing so, the process selection is in analogy to the material selection, which means the multitude of possible processes is also screened by means of constraints and further on ranked.

A quite similar, but partly more diverse material and process selection approach for engineering design (e.g. providing deeper insights into the effects of material properties and manufacturing processes on design) is presented by Farag [6]. Herein, although the strategy for selection materials is almost identical, the fundamental procedure is determined by the need to satisfy design requirements and involves the common four stages: analysis of the performance requirements and creating alternative solutions, initial screening of solutions, comparing and ranking alternative solutions, and finally selecting the optimum solution. In doing so, a striking feature is the partly close connection to the basic product development phases as well as the rudimentary 'true' integrated consideration of material and process.

There are further dedicated process selection methods, such as Swift and Booker [7], in addition to the just mentioned combined material and process selection approaches. Accordingly, this approach derives relevant