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Towards automated joining element design

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Abstract

Product variety and its induced manufacturing complexity remains to increase and therefore greatens challenges for design of joining elements. Historically, joining element design was a paper-based process with incomplete variety documentation and is digitalized only by replacing paper for 3D space. Currently, joining element design remains an ambiguous manual task with limited automation, resulting in long iterative, error prone development trajectories and costly reworks. Thus, processes in practice conflict with required capabilities. Artificial intelligence helps to solve such conflicts by taking over repetitive tasks, preventing human errors, optimizing designs and enabling designers to focus on their core competencies. This paper proposes a novel artificial intelligence method toolbox as a foundation to automate joining element design in manufacturing industries. The methodology aims to incorporate multiple lifecycle requirements including large product variety.

Keywords: Artificial Intelligence; Machine Learning; Automation; Design for Assembly; Joining Elements; Product Variety; Design; Engineering; Commonality; Modular Design; Process selection; Joining Locations; Complexity;

1. Introduction

Product variety (PV) is a growing trend of offering highly configurable products [1] and enables market competitiveness of companies. PV occurs in all types of products [1], but the numbers of variants in automotive

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industry can be immense, e.g. there are up to 10^{24} possible Mercedes-Benz E-Class configurations [2]. PV induces complexity in design and manufacturing and is likely to cause higher costs, lower quality, and delays over the entire product life cycle [1]. Joining is a key process in manufacturing by providing function to a product as a whole and increasing the manufacturability hereof [3]. It enables assembling of smaller cheaper parts into complex components and products [4]. Products easily contain thousands of joining elements (JE) in case of the automotive industry [5]. Due to the transition from a paper-based approach to computer-aided-design (CAD), JE design became an iterative manual time-consuming multi-disciplinary process involving many conflicting requirements. Therefore, JE design is mainly the result of design experience and trial-and-error approaches [6].

An extensive state of the art and research analysis is conducted in still unpublished work of the authors. It stresses the necessity of automated JE design in manufacturing industries considering PV and proposes Artificial Intelligence (AI) methods to be a promising solution path. Literature proposes partial solutions to aspects of JE design, such as joining technology selection [7, 8], topology optimization [9–11] or joining parameter determination [12], but barely considers PV [13]. Modular product design (MPD) is often used to manage PV [2, 14], however such approaches do not consider JE design holistically.

Therefore, this paper presents a novel AI method toolbox for automated JE design in manufacturing industry considering PV requirements. The method toolbox aims to solve issues and requirements from practice based on a target JE design process. To the best of our knowledge, this is the first study that addresses holistic JE design by the use of AI methods.

The paper will address state of the art in section 2, including JE design issues, requirements for automation, state of literature and AI methods in manufacturing industry. Section 3 presents the method toolbox for automated JE design. Section 4 evaluates the toolbox and addresses implementation challenges. Lastly, section 5 contains the conclusion and addresses future work.

2. State of the art

2.1. Practiced process and issues of joining element design

JE design in practice is observed to be a repetitive, ambiguous and complex discipline. The process includes in-depth analyses of variant scenarios and multi-discipline requirement verification. Moreover, authoring results are practical, as the designer is concerned with finding a solution, not the solution. Proper designed JEs require three aspects: 1) technology (e.g. welding or adhesive bonding), 2) locations (e.g. shape or coordinates) and 3) parameters (e.g. diameter, material or object type). Together, these enable downstream processes to continue product development. It is found that designers roughly implement one of three approaches to design an aspect: 1) analysis and application of similar use cases, 2) intuition based design, or 3) minimal design while adhering to standards. Summing it up:

- **Time consumption**. A lot of time on is spend on analysis of joining scenarios due to PV. Moreover, the actual authoring is a rather repetitive task. It leaves little time to spend on challenging tasks that require holistic and creative thinking. Moreover, unaccounted lifecycle requirements, human errors and adaptation to new variants cause unnecessary design iterations.

- **Practical solutions**. As designers have no possibility to find global (business) optima. They design in local space, where it is difficult to consider holistic requirements and design consequences. There are no design tools available nor is there active anticipation of MPD.

2.2. Target process and requirements

The bolded box captions in fig. 1 depict the target process for JE design. The process only requires a starting trigger and result acceptance from a designer. A pre-processing stage determines characteristics of each joining scenario in a joining scene, such as contact regions, constructability and feature classes.