

English Summary

The discrete manufacturing industry is getting increasingly digitalized. As a result, virtual engineering has long been an essential requisite, although conformity is scarce. Mechatronic discrete manufacturing machines are at the heart of the industry, responsible for creating and handling the products from where their value is created. Thus, products are only as good as the machines that produce them. It is, therefore, vital that these machines perform as specified. Virtual engineering increases quality and reduces time to market. However, Small and Medium Enterprises lack the resources and competencies to commence in virtual engineering at the required level. To make things worse, there is essentially no consensus on the requirements for virtual engineering in digital twin-ready mechatronic discrete manufacturing machines, and virtual engineering toolchains are largely inconsistent and sporadically spread.

Therefore, this thesis aims to break these barriers by creating an integrated framework from design to operation, where virtual models are utilized from the machine builder to the end customer. During the research, both generic and vendor-specific solutions have been investigated and tested. While machine complexity is largely case-dependent, much can also be ascribed to the complexity of virtual engineering tools. Comparisons on VE tools should thus be made on the same premises and at the same detail level. This Ph.D. project, therefore, suggests that virtual engineering should be done with high accuracy and on several virtual engineering abstraction levels to mirror reality properly. While uncertainty in the machine design and development increases the number of entities that must be made with high accuracy, the opposite applies when confidence in the solutions is high.

In this research, it has been witnessed how virtual engineering modularization increases the adaptability of the machines and confidence in the solutions. Thus, the development time is reduced. However, it does not mean complexity is eliminated; instead, it's hidden to reduce the number of items that need to be considered at first glance.

The integrated framework presented in this thesis makes changes and modifications feasible as they apply to all virtual engineering abstraction levels, although information sharing across virtual engineering tools could be further optimized. However, this means there must be convergence between the tools, which requires harmonized standards and procedures or full control of the complete virtual value chain. When this is not possible, additional procedures and software integration are necessary, complicating and increasing the development time. Thus, openness in virtual engineering is urgently needed across virtual engineering tools and at the required level.

This thesis has examined the use of virtual tools for the development of digital twin-ready mechatronic discrete manufacturing machines in the production industry. Based on the results, a framework for future virtual engineering of digital twin-ready mechatronic discrete manufacturing machines has been developed and demonstrated. This framework effectively illustrates an integrated virtual engineering value chain from design to operation. It depicts how shared virtual machine modules can facilitate adaptability and increase collaboration between machine builders and end customers. Therefore, the long-run implications of the research are yet to be investigated, although a plan has already been put into action.