DFA in conceptual modular product design

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ABSTRACT

Modular product design, having evolved since its introduction in the 90s, notably through the application of Modular Function Deployment (**MFD**), plays a pivotal role in contemporary manufacturing. The increasing adoption of *reconfigurable* production systems underscores the need for a robust *conceptual phase* in achieving modularity. Considering **assembly** in the conceptual design phase is crucial for maintaining low costs and facilitating manufacturing processes.

This research addresses a critical challenge: the *integration* of modularity and assembly considerations in the conceptual phase. Currently, there is a lack of a clear method for optimizing this phase to achieve profitable and strategic outcomes. The central question guiding this study therefore is as follows. *How can the conceptual phase of modular product design be optimized for both modularity and assembly?*

A *systematic literature review* and *expert consultations* explores the current state of the art concerning product architecture and assembly-related methodologies. The research introduces internal criteria selection for Pugh evaluation, and novel evaluation tables for module interactions to enrich the existing MFD framework. *Iterative trials* with students and potential validation with industry experts refine the proposed methodology.

Results showcase the enriched **MFD/PALMA** methodology, criteria selection, evaluation tables, and trial feedback. The study's significance lies in providing a *benchmark solution* for modular product design, impacting product structures, production systems, and supply chain organization. This methodology is particularly beneficial for industries aiming for cost reduction, faster time-to-market, and efficient production layouts.

In conclusion, the study aims to successfully integrate MFD with DFA in the conceptual phase, contributing to theoretical advancements and providing practical tools for enhanced profitability and efficiency.

OBJECTIVES

By enriching the MFD/PALMA methodology with structured assembly considerations in the conceptual phase, we hypothesize that we can create a benchmark solution for modular product design. This integration will not only positively **impact** the product structure but also **enhance** the efficiency of the production system, supply chain organization, and related aspects. The method will be particularly beneficial for companies striving for cost reduction, faster time-to-market, and efficient production system layouts in the context of mass customization and Industry 4.0 technologies.

Our thesis argues that the most effective approach to conceptual modular product design involves the combination of **MFD** and **DFA**. While MFD, as embodied in the PALMA software from Modular Management AB, establishes modular product architectures based on customer values and product properties, the conceptual phase requires a dual focus on modularity and assembly considerations. By enriching the MFD method with structured assembly considerations, we aim to provide a benchmark solution that not only improves product design but also positively impacts the entire production system, supply chain organization, and related aspects. This approach is crucial for companies striving for cost reduction, faster time-to-market, and efficient production system layouts in the era of mass customization and Industry 4.0 technologies.

MAIN RESEARCH QUESTION

How can the conceptual phase of modular product design be optimized to achieve the most profitable and strategically advantageous outcomes, considering both modularity and Design for Assembly (DFA)?

MATERIALS AND METHODS

The employed research methodology falls in between **Type 3** and **Type 4** of the design research project types proposed by Blessing and Chakrabarti (2009), in their book *DRM, a Design Research Methodology*, which is an established protocol for research in design.

Research clarification is done via a review-based approach, in specific a **SLR**. Descriptive study I is also review based, in the form of a questionnaire/survey to retrieve inputs for modelling. The prescriptive study could be comprehensive, with trial made with students. The descriptive study II could be either initial, or comprehensive to then have a second iteration of the prescriptive study, depending on availability of time and resources. This follows the scheme below.

- Employed a systematic literature review to analyze existing works, gathering insights into *current practices*, *challenges*, and *gaps* related to modular product design, DFA, and their integration.
- Engaged in discussions with industry experts to complement findings from the literature review. Expert insights provided *practical perspectives* and enriched the understanding of real-world challenges and opportunities in conceptual modular product design.
- In the proposed methodology enhancement, *internal criteria* for Pugh evaluation were added to the original proposal. These criteria are the basis for evaluating technical solutions against important factors for assembly in the small.
- Developed new evaluation *tables* and *matrices* for analyzing interactions between modules, specifically focusing on interfaces and connections. This data is crucial for evaluating whether the proposed modular design is suitable for efficient assembly in the large.
- Currently conducting the first of two iterations of trials with students from a focused course at KTH. Collecting data, including *feedback* from both students and industry experts (teachers and Modular Management AB employees), to assess the usability and effectiveness of the proposed software and methodology.
- Based on the feedback received, data will be collected during the refinement process of the proposed model. If feasible, a *final validation iteration* with a company working with Modular Management AB is planned, collecting additional data to ensure practical applicability and effectiveness.

This approach is chosen for the integration between theoretical insights, practical expertise, and iterative refinement through trials. It ensures that the proposed methodology aligns with both academic principles and real-world applicability. The iterative nature allows for continuous improvement based on practical feedback, making it robust.

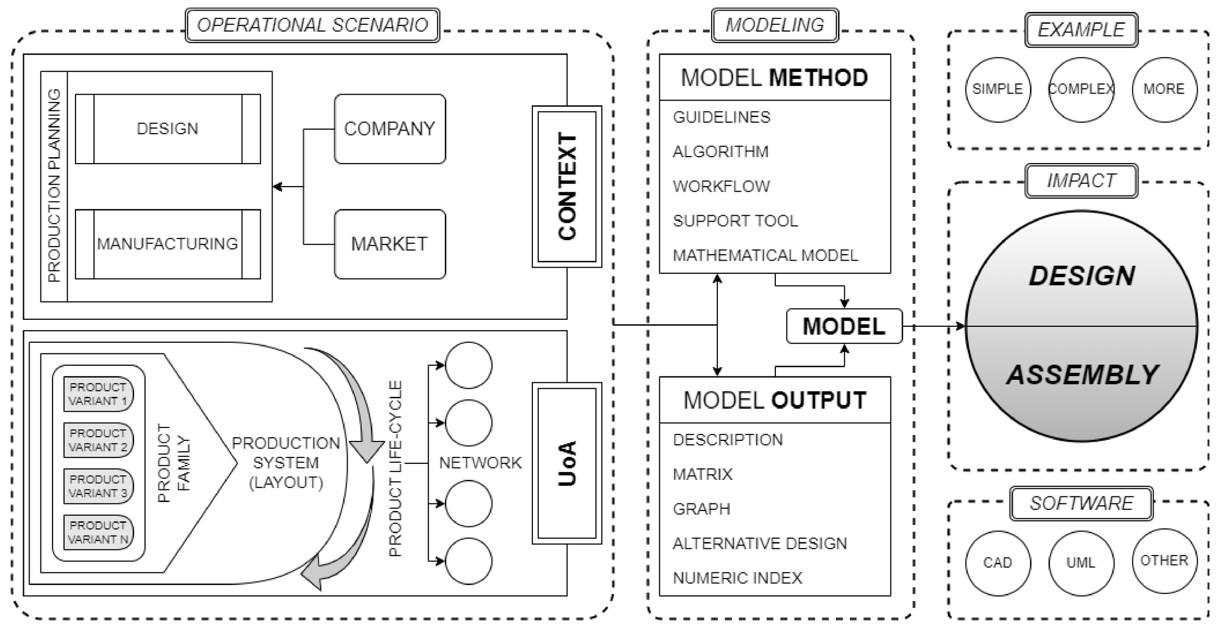
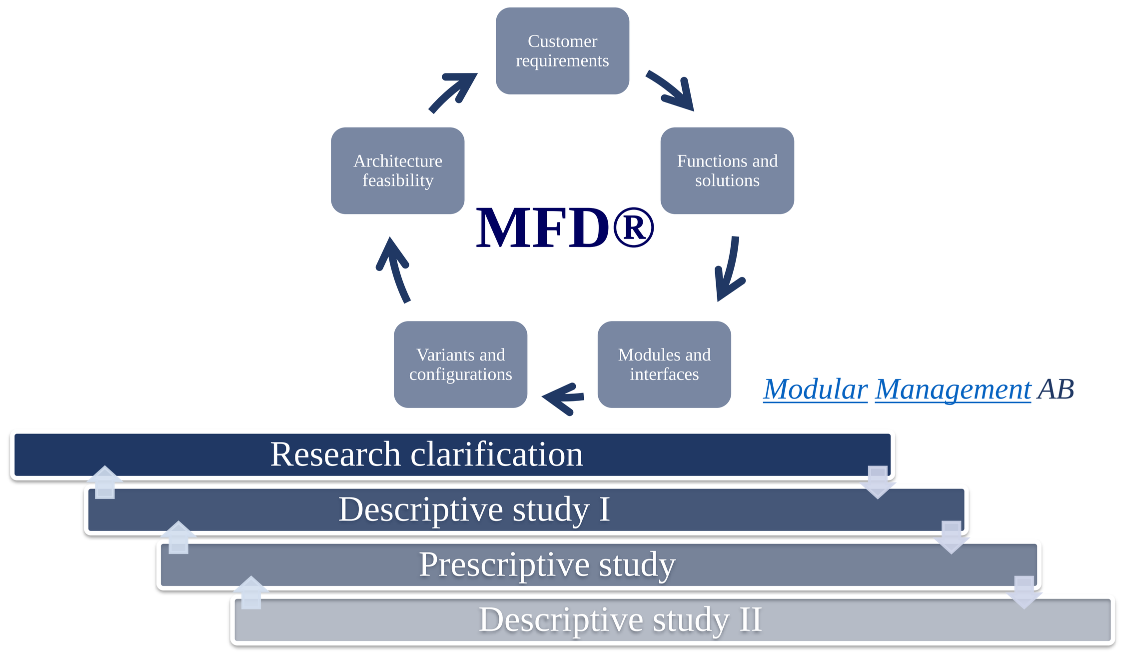


Fig. 1 A framework for model creation for DFA and PA optimization (Monetti and Maffei, 2023)

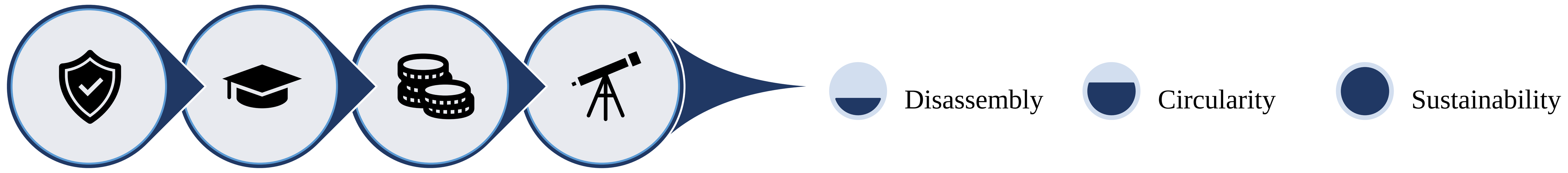


Blessing, L. and Chakrabarti, A., DRM, a Design Research Methodology (2009).

RESULTS

The main results aim to show a positive development and enhancement of the **MFD/PALMA** methodology, its application in evaluating modules for assemblability, and its trial with students to gather user feedback. The secondary objectives provide additional insights into the usability, user perceptions, and practical applicability of the proposed methodology in real-world scenarios. Collectively, these results contribute to the broader understanding of the problem.

- Developed an *enriched version* of the MFD/PALMA methodology with a structured approach for incorporating assembly considerations in the conceptual phase of modular product design.
- Identified and selected internal criteria for Pugh evaluation, enhancing the methodology's ability to *evaluate technical solutions* for assembly.
- Created new evaluation tables/matrices for *analyzing module interactions*, focusing on interfaces and connections. Generated data indicating the suitability of proposed modular designs for efficient assembly.
- Conducting up to two iterations of trials with students, presenting the enhanced methodology and software. Collected feedback from students, teachers, and industry experts to assess *usability* and *effectiveness*.
- Based on trial feedback, *refined* the proposed model, addressing identified issues and improving usability. If feasible, run a final validation iteration with a company working with Modular Management AB.
- Future development will include disassembly consideration in the methodology, so that it will be possible, in the near future, to actively seek to embrace *circularity* and *sustainability* paradigms.

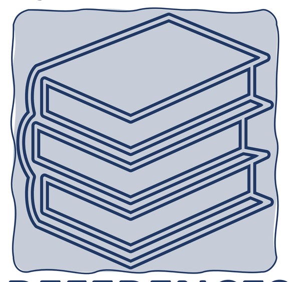


CONCLUSIONS

Modular product design: how to integrate modularity and assembly considerations in the critical conceptual phase?

Industries faces challenges in achieving profitability and strategic success, especially in the era of reconfigurable production systems. Our solution comes in the form of an enriched approach. We enhanced the MFD method with structured assembly considerations. This means we developed a powerful tool that shapes modular product architectures based on customer values and product properties and ensures that individual modules and module structure is easily assemblable. The solution is needed for cost reduction, faster time-to-market, and efficient production, and ultimately helps achieve reconfigurability.

The research helps approach modular product design. Industries now have at their disposal a method that integrates modularity and assembly considerations in the conceptual phase. This is a practical tool that impacts the entire production system layout and efficiency.



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