

Towards Formalization of Assembly Knowledge for Product and Assembly Trade-Off Analysis

Moharram Challenger^{1,3}[2-5436-6070], Albert Rosich²[2-9141-3067], Joachim Denil^{1,3}[2-4926-6737], and Hans Vangheluwe^{1,3}[3-2079-6643]

¹ AnSyMo/CoSys-Lab, University of Antwerp, Belgium

² CoDesignS, Flanders Make, Leuven, Belgium

³ Flanders Make, Leuven, Belgium

{moharram.challenger, joachim.denil, hans.vangheluwe}@uantwerpen.be,
albert.rosich@flandersmake.be

Abstract. The Product-Assembly Co-Design (PACo) project aims at bridging the gap between product design and assembly system design by front-loading of assembly knowledge into the early stages of the product development. Currently, most companies consider assembly aspects later in the design process, often in a manual way, solely relying on the experience of assembly engineers. This leads to numerous design changes causing significant extra costs. PACo user companies expect that applying these co-design methods and tools will lead to improved designs, internal cost reduction (up to 25%), and will allow them to strengthen their market position and keep their production. One of the innovative goals of this project is a software environment for the formalization of assembly knowledge e.g. Design-for-Assembly (DFA) rules, assembly complexity metrics. This paper presents a general overview of the project and is specifically focused on the formalization of assembly knowledge, in the scope of workpackage 3 of the project. The goal of this workpackage is the development of a platform for the formalization and quantification of assembly knowledge such as product and assembly designs as well as DFA rules and assembly complexity metrics. This platform will transform the qualitative definitions of such rules and metrics into a mathematical form, allowing an objective comparison and ranking of different conceptual designs with respect to assembly complexity. Based on this platform, a framework will be developed for the co-design of the product and its assembly system in a semi-automated workflow.

Keywords: Product Design · Assembly Process · Assembly Knowledge · Design-for-Assembly (DFA) · Co-Design · Domain-specific Language

1 PACo Project Overview

The Product-Assembly Co-Design (PACo⁴) project is an ongoing national project in Flanders region, Belgium. It is a collaborative research projects between researchers and industry which is funded by Flanders Make in the scope of design and optimization cluster. Flanders Make is the strategic research centre for the manufacturing industry. The main goal of Flanders Make is realising a top-level

⁴ <https://www.flandersmake.be/en/projects/paco>

research network in Flanders that delivers full support to the innovative projects for manufacturing companies. In this way, it contributes to the new products and production processes that help to realise the vehicles, machines and factories of the future.

PACo project is a SBO (Strategic Basic Research) project and it aims at bridging the gap between product design and assembly system design by front-loading of assembly knowledge into the early stages of the product development [7]. The result will be a software tool and technology to realize the co-design and trade-off analysis between the product performance and ease of assembly. The current industrial context requires companies to aim at a first-time-right, down to lot size 1 production strategy. Hence, considering assembly aspects too late or in trial-and-error way is no longer an efficient option.

All companies involved in the user group of this project indicate a clear need to support their engineers with methods and software tools enabling assessment of assembly complexity in an early design stage, allowing co-optimization of product performance with ease-of-assembly in a quantitative way, and allowing trade-off analysis of various solutions. As these software tools are beyond the state-of-the-art, the research partners will join forces to shift the state-of-the-art in product-assembly co-design. The results of the project will be evaluated with the industrial use cases.

The project duration is 4 years (started in September 2018). It has 5 core-lab partners, see Table 1, from Belgian universities (KULeuven, University of Antwerp and University of Ghent) and research-center (Flanders Make) which play the role of research group in the project. Also, it has 9 industrial partners as the user group of the project. While the user group provides the industrial use cases and industrial challenges in the scope of the project (via 6-monthly user group meetings), the research group addresses these cases and challenges with their innovative research studies and technologies.

Table 1. PACo Project’s research and industrial partners

Partner Title	Organization Name	Type	Role
FM-CoDesignS	Flanders Make Core Lab	Research Center	Project coordinator and WP1 leader
FM-ProductS	Flanders Make Core Lab	Research Center	WP2 leader
AnSyMo/CoSys	Univ. of Antwerp Core Lab	University	WP3 leader
DMMS-D	KULeuven-PMA Core Lab	University	WP4 leader
EEDT	Univ. of Ghent Core Lab	University	WP5 leader
Atlas Copco	Atlas Copco Airpower NV	Industrial partner	Use Case provider
Borit	Borit NV	Industrial partner	Industrial user
CNHi	CNHi Industrial Belgium	Industrial partner	Use Case provider
Noesis	Noesis Solutions	Industrial partner	Industrial user
Reynaers	Reynaers Aluminium	Industrial partner	Industrial user
Siemens	Siemens PLM Software	Industrial partner	Industrial user
Tenneco	Tenneco Inc.	Industrial partner	Industrial user
VHA	Van Hoecke Automation	Industrial partner	Industrial user
Vitalo	Vitalo Global Termoforming	Industrial partner	Use Case provider

The project has 7 workpackages which are shown in Figure 1 demonstrating their interactions with each other. There are 3 management workpackages namely WP1-Management, WP2-Use Cases, and WP-7 Vaporization and Dissemination in the project. Also, there are 4 technical workpackages namely WP3-Formalization of assembly knowledge, WP4-Product optimization, WP5-Assembly system optimization, and WP6-Semi-automated product-assembly co-design. Here, we give a brief description of each technical workpackage.

WP3 aims to keep the knowledge of the product and production system in a systematic way and transform this data to meet the system requirements. This WP, as the information management center of the project, uses software engineering techniques and extends them to apply on PACo project. WP3 has a software-intensive role in the project which is the focus of this paper.

The goal of WP4 is the development of one or more optimization algorithms for the (multi-objective) optimization of early-stage product designs. These designs will be optimized with respect to product performance and/or one or more assembly complexity metrics resulting in a set of (Pareto-)optimal designs.

The aim of WP5 is the development of algorithms for (i) the derivation of assembly steps from the product description, (ii) the optimization of the assembly process (the order in which the different steps will be performed) and (iii) the optimization of the assembly system (the resources performing these steps), all for a given product.

Finally, WP6 intends to develop semi-automated workflows to perform product-assembly co-design. A comparative study will be performed to compare their performance (speed, ease of use, and so on) for the different generic use cases. This allows design teams to select the workflow most suited to their product class.

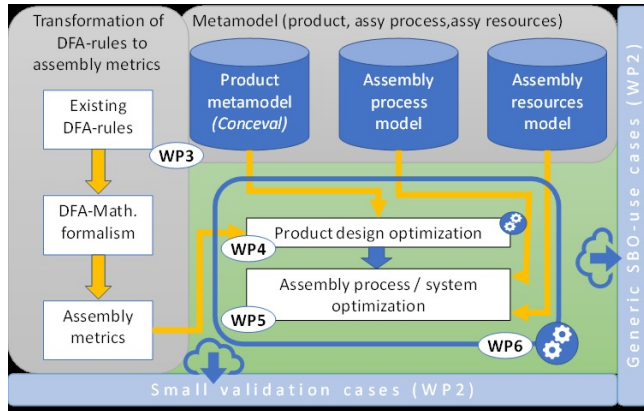


Fig. 1. Workpackages of the project and their interactions

2 Formalization of Assembly Knowledge

Due to the variety of the interacting components and stakeholders in the project, the system is complex (structural complexity) and we need for a systematic way to handle this complexity and to provide: (I) Data integration (II) Data

exchange between design tools (Product design and Assembly process design) and analysis/optimization tools (III) Interaction between the designer and the tools (IV) a Standard interface for a third party integration. WP3 addresses this problem with formalizing the assembly knowledge in this project.

In general, WP3 aims the development of a platform for the formalization and quantification of assembly knowledge such as Design for Assembly (DFA) [1] rules and assembly complexity metrics. This platform will transform the qualitative definitions of such rules and metrics to a mathematical form, allowing an objective comparison and ranking of different conceptual designs with respect to assembly complexity. The algorithms/procedures for doing these transformations will be provided in the scope of WP5 [9]. For this purpose, the results of recently finished project called Conceval [4] will be used. Also, the metrics to assess the product as well as their computation approach will be provided in the scope of WP4. For this purpose, the results of project called Conceptdesign [3] will be used.

Assembly knowledge-base aims to keep the all data required for a product and its assembly process to be analyzed and optimized later, see Figure 2. This data will be provided/used by the other components such as CAD tools (e.g. FreeCAD and/or optimization tools such as Minizinc and Julia).

To provide a formal and systematic approach to keep the knowledge in the system and provide the aforementioned requirements, it is decided to provide the data model using Model-driven Engineering (MDE) techniques to later analysis and optimisation. This will be realized by developing 3 Domain-specific Languages (DSL) [5][6] for Design, Assembly, and DFA rules which are called DSL4Design, DSL4Assembly, and DSL4Rule respectively. The data exchange between different components will be provided by model transformations. In this way, the knowledge base will provide interfaces between designers and standard APIs for tool developers who want to extend the system with the new CAD tools or the new optimization tools. This WP will be developed by AnSyMo group and CoSys Lab (called AnSyMo/CoSys core-lab) at the University of Antwerp and CoDesignS Lab at Flanders Make.

To implement the above-mentioned DSLs, the concept dictionary is provided by doing commonality and variability analysis collaboratively with all partners. This concept dictionary paves the way for developing the domain-specific metamodel. The metamodel will be used to instantiate some of the user case studies to evaluate the comprehensiveness and expressiveness of the metamodel. The metamodel can be used directly or can be transformed to a context-free grammar to play the role of abstract syntax of the DSLs. Based on this abstract syntax, text/graphical concrete syntaxes will be provided to develop the editors for the DSLs. These editors can be extended by adding domain rules as constraint checking feature of the languages. Later, the semantics of the languages will be defined by providing the transformation rules for each language to transform the models to the target tool specifications (such as Minizinc).

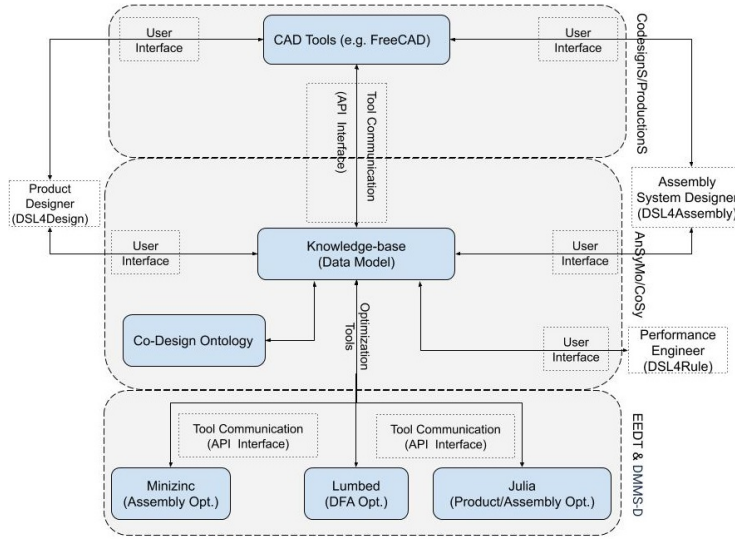


Fig. 2. High-level architecture of the project

3 Expected Outcome of the project

The potential innovative results of the PACo project can be characterized as follows:

- a software environment for the formalization of assembly knowledge (e.g. DFA rules, assembly complexity metrics).
- tools and algorithms for automated multi-objective optimization of the early-stage design of a product, taking into account the product performance and its assembly complexity.
- tools and algorithms to automatically find the optimal assembly process (order of steps) and assembly system (resources allocation), for a given early-stage product design
- a framework for the co-design of both product and its assembly system in a semi-automated workflow.

The proposed approach will provide a semi-automatic mechanism for design of the product by considering both, product performance and the assembly process, see Figure 3. In the resulting methodology, the users (design engineers) will interact with the algorithms while designing the product or after finalizing the design. Then, the methodology will be able to evaluate the performance of the product as well as assess the assembly process required to produce the product. It is foreseen that the user can interact with the algorithm in this evaluation process in order to provide input when required. Later, the system can suggest optimized product design and assembly sequence considering the already adjusted evaluation criteria. Finally, the user will select/confirm the suggested choice(s) and continue the design iterations. By employing the proposed methodology, the trade-off analysis between product performance and assembly process will be formally and consistently addressed.

The companies expect that applying this methodology, empowered by co-design [8] methods and other techniques such as ontologies [2], will lead to improve the designs, reduce internal cost (up to 25%), and allow the companies to strengthen their market position and keep their production in Flanders.

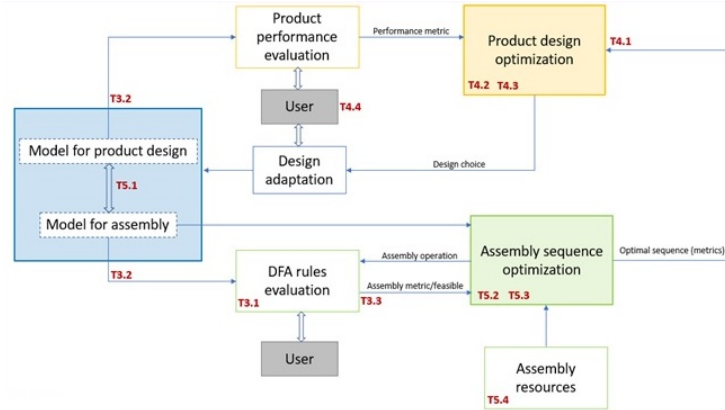


Fig. 3. Interaction with the resulting system

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References

1. Boothroyd, G., Dewhurst, P., Knight, W.A.: *Product Design for Manufacture and Assembly*, Revised and Expanded. CRC press (2001)
2. Challenger, M.: The Ontology and Architecture for an Academic Social Network. *International Journal of Computer Science Issues (IJCSI)* **9**(2), 22 (2012)
3. Flanders Make: *Model-based Conceptual Design and Synthesis (ConceptDesign)*. Flanders Make ICON project, 2014-2017
4. Flanders Make: *Multi-attribute Concept Evaluation of Lightweight Structures (ConceptEval)*. Flanders Make ICON project, 2017-2019
5. Kardas, G., Tezel, B.T., Challenger, M.: Domain-specific Modelling Language for Belief–Desire–Intention Software Agents. *IET Software* **12**(4), 356–364 (2018)
6. Marand, E.A., Marand, E.A., Challenger, M.: DSML4CP: A Domain-specific Modeling Language for Concurrent Programming. *Computer Languages, Systems & Structures* **44**, 319–341 (2015)
7. Marconnet, B., Demoly, F., Monticolo, D., Gomes, S.: An Assembly Oriented Design and Optimization Approach for Mechatronic System Engineering. *International Journal for Simulation and Multidisciplinary Design Optimization* **8**, A7 (2017)
8. Vanherpen, K., Denil, J., De Meulenaere, P., Vangheluwe, H.: Ontological Reasoning as an Enabler of Contract-based Co-design. In: *International Workshop on Design, Modeling, and Evaluation of Cyber Physical Systems*. pp. 101–115. Springer (2016)
9. Vanherpen, K., Denil, J., Vangheluwe, H., De Meulenaere, P.: Model Transformations for Round-trip Engineering in Control Deployment Co-design. In: *Proceedings of the Symposium on Theory of Modeling & Simulation: DEVS Integrative M&S Symposium*. pp. 55–62. Society for Computer Simulation International (2015)