Exploring Architectural Design Decisions in Industry 4.0: A Literature Review and Taxonomy

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Abstract: The full version of this paper is published at the Foundation Track of ACM/IEEE 24th International Conference on Model Driven Engineering Languages and Systems (MODELS), 2021. Architectural design decisions, such as service deployment and composition, plant layout synthesis, or production planning, are an indispensable and overarching part of an industrial manufacturing system design. In the fourth industrial revolution (Industry 4.0), frequent production changes trigger their synthesis, and preferably optimization. Yet, knowledge on architecture synthesis and optimization has been scattered around other domains, such as generic software engineering. We take a step towards synthesizing current knowledge on architectural design decisions in Industry 4.0. We developed a taxonomy describing architectural models, design decisions, and optimization possibilities. The developed taxonomy serves as a guideline for comparing different possibilities (e.g., application of different optimization algorithms) and selecting appropriate ones for a given context. Furthermore, we reviewed and mapped 30 relevant research works to the taxonomy, identifying research trends and gaps. We discuss interesting, and yet uncovered topics that emerged from our review.

Keywords: architecture synthesis; optimization; taxonomy; design space exploration; model-based development; Industry 4.0

1 Summary

The design of industrial manufacturing system comprises different architectural design decisions (ADDs), such as the deployment of different software components (SWCs) to hardware components (HWCs), production services composition, plant layout determination, or production planning (i.e., the decision of which station should perform which production step) [KKZ14]. Contrary to current manufacturing systems, the fourth industrial revolution, known as Industry 4.0 (I40), envisions an unplanned changeability of optimized production processes without significant downtime [WCB17]. Different I40 scenarios, such as lot-size-one production and plug-and-produce, frequently influence and trigger the synthesis of different ADDs, making the ADDs synthesis *an indispensable* and *overarching* part of the I40.

This increased importance of architecture synthesis and optimization (ASO) in I40, and numerous established ASO solutions from other domains [Al13], drive *the need for an*

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overview of ASO. Such an overview would list and clarify existing problems in the domain, and at the same time, present fitting approaches and alternatives according to specific user's needs.

We take a step towards synthesizing current knowledge on ASO. We differ from existing works (e.g., [Al13]) by providing a review and analysis of the ASO in the I40 context – considering domain-specific modeling approaches, design decisions, use cases, etc. We characterize the state of the art of ASO in I40 by reviewing and analyzing 30 research papers.

We develop a taxonomy that characterizes architectural models, ADDs, and optimization possibilities. The resulting taxonomy serves as a guideline for a comparison of different possibilities (e.g., application of different optimization algorithms) and a subsequent selection of the appropriate possibility for the given context. Furthermore, we identify the following research trends and gaps:

- Deployment and production planning are the most often conducted ADDs, usually done together with scheduling and matching ADDs, respectively.
- Multi-dimensional ADDs are mostly conducted sequentially.
- Compositionally and incrementally searching ADDs are neglected, as well as application of meta-heuristics and multi-objective optimization.
- Timing aspects are the most often considered in different I40 ASO problems, whereas the reconfigurability and reliability constraints and objectives are almost neglected.
- The majority of papers use the benefits of Model-based Design (MbD) and apply different models as input for ASO.
- Domain-specific models are the most popular, especially for modeling software and hardware architectures.

2 Data Availability

The full version of this paper [TDV21] is published at the Foundation Track of ACM/IEEE 24th International Conference on Model Driven Engineering Languages and Systems (MODELS), 2021. Private preprint paper and accompanying material can be requested for personal use at the ResearchGate website[4].

[4] https://www.researchgate.net/publication/354473962_Exploring_Architectural_Design_Decisions_in_Industry_40_A_Literature_Review_and_Taxonomy

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