Scientific Methods, Assignment 3

Fahim Shahria, Hampus Fink Gärdström, Henrik Prüß
Henrik Schwarz, Tom Bourjala, Tomas Soucek

University of Southern Denmark, SDU Software Engineering, Odense, Denmark
Email: {fasha23,hgard20,hepru23,hschw17,tobou23,tosou23}@student.sdu.dk

I. Background

Industry 4.0 offers potentials for manufacturing businesses. It allows for flexible production lines that realize quality attributes like interoperability, availability and deployability. In other words, new machines can be added to an existing production line, the production line has close to 100

However, the software system revolving around the production line must be systematically planned. The software system must coordinate the different production machines because each machine only knows about its own part of the production line. For instance, the machine attaching tires to a bike has no clue of what a bell is nor how to attach it. Another challenge handled by the software system is the scheduling of production runs. It acts as a load balancer, checking the current capacity of the production lines, and scheduling new production runs if enough capacity is available.

Besides the functional requirements the software system must address also non-functional requirements to achieve the mentioned quality attributes. For instance, availability requires a high degree of fault-tolerance or replication to keep the system running in the case of failure. Solutions for those problems already exist. for example in the form of architectural tactics and design patterns. Therefore, it should be investigated how software architecture helps to achieve the described quality attributes in a Industry 4.0 environment. The present Systematic Literature Review aims to analyze existing contributions in order to provide a overview over the current state of research.

II. Research questions

The study identifies the following requirements for the production system, resembling the quality attributes interoperability, availability and deployability:

1) Production software must be able to exchange and coordinate information to execute a production and change production
2) Production software must run 24/7
3) Production software must be continuously deployable

Deducted from the requirements, the following research questions are defined:

1) How can different architectures support the stated production system requirements?
2) Which architectural trade offs must be taken due to the technology choices?

III. Search strategy

In order to start our search for literature, we selected an initial research paper. The initial paper was chosen based on a manual search looking for keywords like 'Software Architecture' and 'Industry 4.0'. The selected paper is A Reconfigurable Industry 4.0 Middleware Software Architecture

After selecting our initial paper, we proceeded with snowballing and an automated search. This part will focus on the snowballing part that has been conducted before the automated part. We opted to employ citation analysis as a fundamental technique for our literature review. First, we initiated the forward snowballing process. Only one paper was identified that had cited our initial paper, titled Designing and Evaluating Interoperable Industry 4.0 Middleware Software Architecture: Reconfiguration of Robotic System

Subsequently, we engaged in backward snowballing, which yielded, in terms of citations, results more worthy of mentioning. We initially encountered a total of 40 resources, encompassing both academic and non-academic sources. We then applied specific criteria to narrow this pool down to 21 papers. Our criteria primarily focused on retaining especially academic papers, with a single exception for a non-academic source. Additionally, we excluded technology manuals and conducted a brief review of papers that did not appear relevant based on their title or abstract.

In cases where we identified content of interest, the articles were retained for further consideration. Otherwise, they were excluded from our final selection.

The automatic search started by taking the papers from the snowballing and then extracting relevant or related keywords to our topic. Out of those keywords we selected keywords we wanted to use for our search string. These selected keywords where then grouped into three groups:

1) Software Engineering related
2) Industry related
3) Quality attribute related

All of the keywords were OR chained (K1 OR K2 … OR Kn) and the groups where and chained (G1 AND G2 AND G3). This resulted in the following search string:

```
(systems architecture OR distributed
OR Peer-to-peer computing OR production
engineering computing OR distributed
middleware OR software architecture
OR Internet of Things OR middleware
interoperability OR interoperability
levels OR cyber-physical systems)
AND (industry 4.0 OR I4.0 research
platform OR I4.0 laboratory ) AND (QA OR
Quality Attribute OR Quality Attribute
Requirements OR Quality Attribute Workshop
OR Quality Attribute Scenario)`
```

We searched the IEEE database with only conference- and journal-papers from 2017 and forward which resulted in 22 papers.

IV. Study selection

For our inclusion criteria we have selected to choose papers that are peer-reviewed since we want it to be validated by other researchers. The papers should also be from journals or conferences since it adds authenticity and they should be related to the research question. We choose to exclude papers that were non-academic or less rigorous (bachelor projects).

Inclusion criteria	Exclusion criteria
Only peer-reviewed papers	Bachelor projects
Only journal or conference papers	Tutorials, keynotes, work-in-progress
Related to software architecture or Industry 4.0	

Table I: Inclusion and exclusion criteria

V. Study selection procedure

These papers where filtered based on their title and abstracts relevance to our topic which resulted in 7 papers. The process can be seen in table II.

Strategy step	Papers left
Excluding papers based on their abstract and title	22
2 people excluded the rest of the papers based on relevance and rigour	7

Table II: Filter operations for the papers

VI. Study Assessment Checklist and procedures

For the papers we selected the follow criteria as criteria for assessing quality of the papers:

Does the paper address	industry 4.0	Software architecture	Quality attributes
Paper 1[1]	x	x	
Paper 2[2]	x	x	
Paper 3[3]	x	x	x
Paper 4[4]	x	x	x
Paper 5[5]	x	x	
Paper 6[6]	x	x	
Paper 7[7]	x	x	

VII. Data extraction

To extract data we used an adapted version of the data extraction form proposed by Dybå and Dingsøyr [8]. The form splits into two parts, one dealing with the study metadata and one dealing with the specific findings of the study. We extracted the data for each article chosen from the earlier steps and put the data into a extraction form. You can find the filled extraction forms in the appendix A. The extracted data is synthesized in the next section.

VIII. Synthesis of data

All of the selected papers deal with the domain of Industry 4.0. In addition, they should investigate the use of software architecture in the context of Industry 4.0. However, the level of addressing software architecture varies between the different papers. After extracting the data, it became evident that some papers had their main focus on incorporating software architecture with Industry 4.0, while others only briefly mentioned aspects of software architecture.

Beginning with the papers focussing on software architecture, two papers address the role of attribute-driven design (ADD) [3][5]. [5] utilizes ADD to incrementally create a software architecture suited for data management in the Industry 4.0 domain. The architecture specifically addresses quality attributes like maintainability and scalability, helping to manage the data which is created by smart factories.

Thramboulidis et al. propose integrating the architectural pattern of microservices into the domain of Industry 4.0 [7]. They argue that microservices allow for re-configuration at runtime, i.e. addressing the quality attribute of deployability. Production machines can be added, updated and removed without having to stop the production process. However, using microservices introduces latency which is already a challenge in Industry 4.0.

Another paper focuses on the performance quality attribute and flexibility quality attribute of software systems in Industry 4.0, focusing on the networking part of the system [6]. Different patterns and algorithms are proposed to achieve both, performance and flexibility. [4] illustrates how to prototype a software architecture in the domain of Industry 4.0 in order to address quality attributes like interoperability.

[1], [2], [3] provide additional information about software systems in the context of Industry 4.0, while referencing software architecture to fulfill system requirements more implicit than the aforementioned papers.

Overall, there are multiple sources that investigate the use of software architecture in order to address Industry 4.0 system requirements. However, many papers only mention aspects of software architecture without proposing implementable solutions for Industry 4.0 systems. Consequently, more research in the field of software architecture in the context of Industry 4.0 is required.

References

[1] Steny Ann Sabu and Ciby Thomas. "Industry 4.0 and Sustainability in Through Life Smart Manufacturing". In: *2022 Second International Conference on Next Generation Intelligent Systems (ICNGIS)*. 2022 Second International Conference on Next Generation Intelligent Systems (ICNGIS). July 2022, pp. 1–6. DOI: 10.1109/ICNGIS54955.2022.10079768. URL: https://ieeexplore.ieee.org/document/10079768 (visited on 10/22/2023).

[2] Richard French, Michalis Benakis, and Hector Marin-Reyes. "Intelligent sensing for robotic re-manufacturing in aerospace — An industry 4.0 design based prototype". In: *2017 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS)*. 2017 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS). Oct. 2017, pp. 272–277. DOI: 10.1109/IRIS.2017.8250134. URL: https://ieeexplore.ieee.org/document/8250134 (visited on 10/22/2023).

[3] Tarik Terzimehić. "Architecture Synthesis for Optimized and Flexible Production". In: *2022 IEEE/ACM 44th International Conference on Software Engineering: Companion Proceedings (ICSE-Companion)*. 2022 IEEE/ACM 44th International Conference on Software Engineering: Companion Proceedings (ICSE-Companion). ISSN: 2574-1926. May 2022, pp. 251–255. DOI: 10.1145/3510454.3517057. URL: https://ieeexplore.ieee.org/document/9793810 (visited on 10/22/2023).

[4] Birgit Vogel-Heuser, Christian Diedrich, Dorothea Pantförder, et al. "Coupling heterogeneous production systems by a multi-agent based cyber-physical production system". In: *2014 12th IEEE International Conference on Industrial Informatics (INDIN)*. 2014 12th IEEE International Conference on Industrial Informatics (INDIN). ISSN: 2378-363X. July 2014, pp. 713–719. DOI: 10.1109/INDIN.2014.6945601. URL: https://ieeexplore.ieee.org/document/6945601 (visited on 10/22/2023).

[5] Eduardo A. Hinojosa-Palafox, Oscar M. Rodríguez-Elías, José A. Hoyo-Montaño, et al. "Towards an Architectural Design Framework for Data Management in Industry 4.0". In: *2019 7th International Conference in Software Engineering Research and Innovation (CONISOFT)*. 2019 7th International Conference in Software Engineering Research and Innovation (CONISOFT). Oct. 2019, pp. 191–200. DOI: 10.1109/CONISOFT.2019.00035. URL: https://ieeexplore.ieee.org/document/9105415 (visited on 10/22/2023).

[6] Naresh Ganesh Nayak, Frank Dürr, and Kurt Rothermel. "Software-defined environment for reconfigurable manufacturing systems". In: *2015 5th International Conference on the Internet of Things (IOT)*. 2015 5th International Conference on the Internet of Things (IOT). Oct. 2015, pp. 122–129. DOI: 10.1109/IOT.2015.7356556. URL: https://ieeexplore.ieee.org/document/7356556 (visited on 10/22/2023).

[7] *Cyber-physical microservices: An IoT-based framework for manufacturing systems*. URL: https://ieeexplore.ieee.org/document/8387665 (visited on 10/22/2023).

[8] Tore Dybå and Torgeir Dingsøyr. "Empirical studies of agile software development: A systematic review". In: *Information and Software Technology* 50.9 (Aug. 1, 2008), pp. 833–859. ISSN: 0950-5849. DOI: 10.1016/j.infsof.2008.01.006. URL: https://www.sciencedirect.com/science/article/pii/S0950584908000256 (visited on 10/22/2023).

Appendix A
Data extraction forms

Table III: Industry 4.0 and Sustainability in Through Life Smart Manufacturing - Data extraction

Study description	Study identifier	
	Date of data extraction	2023-10-20
	Bibliographic reference	S. A. Sabu and C. Thomas, “Industry 4.0 and Sustainability in Through Life Smart Manufacturing,” in 2022 Second International Conference on Next Generation Intelligent Systems (ICNGIS), Jul. 2022, pp. 1–6. doi: 10.1109/ICNGIS54955.2022.10079768.
	Type of article	Conference Paper
	Study aims	- “In this review paper, major challenges and scope for implementing the Fourth Industrial Revolution technologies, sustainability in through-life smart manufacturing and the future scope of research areoutlined”
	Objectives	- Discuss concepts, technologies driving forces and implementation barriers in industry 4.0 - Outline what sustainability is in manufacturing - Look at threats in the field of smart manufacturing and industry 4.0
	Design of study	Qualitative
	Research hypothesis	- “Henceforth, a well-defined change management 4.0 must be effectively established as per the standards of Quality 4.0 in order to mitigate the evolved gaps”
	Aspects of Industry 4.0 tackled in study	- Driving forces - Challenges of different aspects of industry 4.0
	Aspects of Software Architecture tackled in study	- Mentions concepts such as AI, big data, Cloud computing, IoT, Autonomous robots
	Data analysis	Qualitative
Study findings	Findings and conclusions	- The big amounts of data that industry 4.0 leads to can have bad consequences for green and sustainable smart manufacturing and industry 4.0
	Validity	- Published in journal “2022 Second International Conference on Next Generation Intelligent Systems (ICNGIS)”
	Relevance	- Introduction to industry 4.0 - Current technologies used in industry 4.0

Study description	Study identifier	
	Date of data extraction	2023-10-20
	Bibliographic reference	R. French, M. Benakis, and H. Marin-Reyes, “Intelligent sensing for robotic re-manufacturing in aerospace — An industry 4.0 design based prototype,” in 2017 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS), Oct. 2017, pp. 272–277. doi: 10.1109/IRIS.2017.8250134.
	Type of article	Conference paper
	Study aims	“The aim of this paper is to give a first insight into the challenges of the development of an Industry 4.0 prototype system and an evaluation of first results of the operational prototype”
	Objectives	- Create a smart robot manufacturing system using 4.0 - Reduce cost and human error in the reparation of the jet blades -
	Design of study	Qualitative
	Research hypothesis	A proposed autonomous robotic system for the re-manufacturing of turbofan jet engine blades is currently under development, aiming to eliminate human error and increase the successful repair yield up to 100%
	Aspects of Industry 4.0 tackled in study	- Using robots, IoT and IoP (Internet of people) to solve the problem - Data management
	Aspects of Software Architecture tackled in study	- Architecture of a system - Quality attributes - Communication diagrams
	Data analysis	Quantitative
Study findings	Findings and conclusions	- The data produced from using industry 4.0 is valuable to the company/system - Using industry 4.0 and its concepts help with better product quality and quality assurance
	Validity	- Published in “2017 IEEE International Symposium on Robotics and Intelligent Sensors (IRIS)” - Cited by 12 people - Peer reviewed? (I only looked for peer reviewed papers but can’t find it on the page of the paper)
	Relevance	- Inspiration for creating a system - Research - Learning how to structure diagrams and papers

Table IV: Intelligent sensing for robotic re-manufacturing in aerospace — An industry 4.0 design based prototype - Data extraction

Study description	Study identifier	
	Date of data extraction	2023-10-20
	Bibliographic reference	T. Terzimehić, "Architecture Synthesis for Optimized and Flexible Production," in 2022 IEEE/ACM 44th International Conference on Software Engineering: Companion Proceedings (ICSE-Companion), May 2022, pp. 251–255. doi: 10.1145/3510454.3517057.
	Type of article	Conference paper
	Study aims	Propose a Satisfiability Modulo Theories (SMT)-based framework for joint synthesis and optimization of multi-dimensional ADDs using industrial automation domain models (e.g., plant topology, product recipes, stations capabilities, etc.).
	Objectives	- Create a framework for creating flexible architecture - Automate the process creating ADD architecture for industry 4.0 to reduce the need of doing it manual every time - Reduce downtime while increasing reconfigurability
	Design of study	Qualitative
	Research hypothesis	This research should bring following benefits for the practitioners and researchers: 1) reduction of engineering effort for conducting different ADDs; 2) improvement of different quality attributes (e.g., production performance, reconfigurability, reliability, etc.); 3) guideline/support for a practitioner in choosing ADDs workflow to improve given quality attributes.
	Aspects of Industry 4.0 tackled in study	- Reconfigurability of production steps and machines - Interconnected systems
	Aspects of Software Architecture tackled in study	- ADD architecture - Optimization of software and hardware system - Quality attributes such as reliability and others
	Data analysis	Qualitative
Study findings	Findings and conclusions	- There is a research gap currently within creating Architecture Synthises and Optimization (ASO)
	Validity	Published in "2022 IEEE/ACM 44th International Conference on Software Engineering: Companion Proceedings (ICSE-Companion)"
	Relevance	- ADD related considerations - Research gaps within ADD

Table V: Architecture Synthesis for Optimized and Flexible Production - Data extraction

Study description	Study identifier	
	Date of data extraction	2023-10-20
	Bibliographic reference	"Coupling heterogeneous production systems by a multi-agent based cyber-physical production system — IEEE Conference Publication — IEEE Xplore." Accessed: Oct. 20, 2023. [Online]. Available: https://ieeexplore-ieee-org.proxy1-bib.sdu.dk/document/6945601
	Type of article	Conference Paper
	Study aims	"This paper proposes an approach that implements the quickly evolving concept of Cyber-Physical Systems for the special case of production systems by means of software agents."
	Objectives	- Address current and future flexibility problems in I40 - Use Cyber-physical Production System(CPPS) components to create Cyber-Physical System(CPS)
	Design of study	Qualitative
	Research hypothesis	Using heterogeneous production facilities inside an architecture for Cyber-Physical Production System (CPPS) compounds for cyber-physical systems will increase flexibility within Industry 4.0
	Aspects of Industry 4.0 tackled in study	- IoT, Interoperability, reconfigurability
	Aspects of Software Architecture tackled in study	- Architecture prototyping - Scenarios - Communication diagrams
	Data analysis	Qualitative
Study findings	Findings and conclusions	- A common standard should be created for the communication and creation of properties in these kind of cyber physical systems - The author acknowledges that their solution are still missing some improvements like middleware - Their initial design is good but there are a lot of new challenges within the topic of cyber-physical systems that arose from their prototype
	Validity	- Peer reviewed - Published in "2014 12th IEEE International Conference on Industrial Informatics (INDIN)" - Cited by 74 papers
	Relevance	- Very good example of an architecture prototype - Great inspiration and example for how to handle communication and reconfiguration of cyber-physical systems so that they are more flexible

Table VI: Coupling heterogeneous production systems by a multi-agent based cyber-physical production system - Data extraction

Study description	Study identifier	
	Date of data extraction	14.10.2023
	Bibliographic reference	E. A. Hinojosa-Palafox, O. M. Rodríguez-Elías, J. A. Hoyo-Montaño and J. H. Pacheco-Ramírez, "Towards an Architectural Design Framework for Data Management in Industry 4.0," 2019 7th International Conference in Software Engineering Research and Innovation (CONISOFT), Mexico City, Mexico, 2019, pp. 191-200, doi: 10.1109/CONISOFT.2019.00035.
	Type of article	Conference article
	Study aims	- "Propose the design of a guided architecture, following good architectural design practices of software engineering, to facilitate the design and implementation of software-based solutions for industry 4.0 with a focus on data management"
	Objectives	- Describe state of the art architectural design in Industry 4.0 - Propose a guided architecture
	Design of study	- Designing an architecture for Industry 4.0 by applying ADD - Description of the design process
	Research hypothesis	"Having a reference architecture for the development of software-based solutions for data management in the context of Industry 4.0 could be very useful to facilitate the development of such systems in the industry."
	Aspects of Industry 4.0 tackled in study	- Cyber-physical systems - IoT technologies
	Aspects of Software Architecture tackled in study	- Attribute Driven Design (ADD) for designing the guided architecture - Quality (data management) attributes - Quality attribute scenarios - Maintenance, Repair, Overhaul (MRO)
	Data analysis	- Qualitative
Study findings	Findings and conclusions	- Proposed architecture (based on Lambda reference architecture) addresses quality attributes (challenges) like resource management, scalability and performance - Apply ADD to create a architecture based on requirements, quality attribute scenarios and reference architectures
	Validity	- Paper from 2019 - Only cited 4 times according to IEEE db
	Relevance	- Research - Practice (how can the industry adopt Industry 4.0 faster by using the described architecture)

Table VII: Towards an Architectural Design Framework for Data Management in Industry 4.0 - Data extraction

Study description	Study identifier	
	Date of data extraction	14.10.2023
	Bibliographic reference	N. G. Nayak, F. Dürr and K. Rothermel, "Software-defined environment for reconfigurable manufacturing systems," 2015 5th International Conference on the Internet of Things (IOT), Seoul, Korea (South), 2015, pp. 122-129, doi: 10.1109/IOT.2015.7356556.
	Type of article	Conference article
	Study aims	- Propose a solution to improve the flexibility of manufacturing systems
	Objectives	- Provide a system that can provide flexibility without sacrificing essential QoS properties - Develop methods for flexible time-sensitive networking suitable for reconfigurable manufacturing systems
	Design of study	- Discussion/Evaluation of network algorithms
	Research hypothesis	"software-defined factory fills these research gaps by creating highly flexible ICT infrastructures for reconfigurable manufacturing systems that provide the desired QoS guarantees for the manufacturing systems, especially with respect to the networking domain"
	Aspects of Industry 4.0 tackled in study	- Networking (real-time communication) - Cyber-physical systems
	Aspects of Software Architecture tackled in study	- Quality of Service (QoS) - Re-configurability
	Data analysis	Qualitative / Quantitative (measuring times)
Study findings	Findings and conclusions	- Normally, there is tradeoff between performance and flexibility when it comes to software architectures for manufacturing systems $\rightarrow$ paper proposes an environment to overcome the tradeoff: software-defined environment (SDE) - There are routing algorithms to that help achieve both re-configurability and performant communication
	Validity	Paper of 2015
	Relevance	- Main focus of the paper is networking - But still, the paper includes some nice statements about flexibility/configurability of Cyber-physical systems

Table VIII: Software-defined environment for reconfigurable manufacturing systems - Data extraction

Study description	**Study identifier**	
	Date of data extraction	14.10.2023
	Bibliographic reference	K. Thramboulidis, D. C. Vachtsevanou and A. Solanos, "Cyber-physical microservices: An IoT-based framework for manufacturing systems," 2018 IEEE Industrial Cyber-Physical Systems (ICPS), St. Petersburg, Russia, 2018, pp. 232-239, doi: 10.1109/ICPHYS.2018.8387665.
	Type of article	Conference article
	Study aims	Adopting the concept of microservices to the domain of Industry 4.0
	Objectives	- Provide a framework enabling the adoption of microservices to the domain of Industry 4.0 - Transforming legacy plants into smart plants using microservices - Use microservices to make plant parts individually deployable (at runtime!) - Semi-automate the development process for industrial engineers who are no experts in software development
	Design of study	- (Systematic) Literature Review - Create and describe a framework - 2 Case studies to validate the framework
	Research hypothesis	"The potential of this new paradigm has been identified and we claim that the microservice paradigm will have a significant impact on the way future manufacturing systems will be developed. Thus, in this paper we propose the integration of IoT technologies with the microservice architecture and examine alternative scenarios for their exploitation."
	Aspects of Industry 4.0 tackled in study	- Cyber-physical systems - IoT technologies
	Aspects of Software Architecture tackled in study	- Microservice architecture - Service Discovery pattern - Orchestration / Choreography pattern
	Data analysis	Qualitative
Study findings	Findings and conclusions	- Microservices address the challenge of deployability by allowing to re-configure or deploy new services at runtime (without interrupting operation) - Service Discovery helps to reduce complexity with service orchestration. Services can be simply defined in the Service Discovery registry, thus if a specific kind of service is requested it will be provided by the registry (i.e. the consumer does not have to know the specific service, but instead the specification of a service) - Use of microservices and containers introduces latency which is critical in Industry 4.0 $\rightarrow$ future frameworks/libraries might address this problem
	Validity	Article from 2018. The state of microservices is different today. E.g. the latency issues with microservices described in this article might have been already solved.
	Relevance	Research, applied to two case studies

Table IX: Cyber-physical microservices: An IoT-based framework for manufacturing systems - Data extraction